# NAVAL POSTGRADUATE SCHOOL

Monterey, California


# THESIS

BASE-LINE CALIBRATIONS OF THE
MINI-RANGER III AND THE ROLE OF SIGNAL
STRENGTH IN CORRECTING REAL-TIME
HYDROGRAPHIC POSITION DATA

by


Bruce F. Hillard


June 1986

Thesis Advisor: Glen R. Schaefer

SECURITY CLASSIFICATION OF THIS PAGE

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a REPORT SECURITY CLASSIFICATION | 1b. RESTRICTIVE MARKINGS |
| 2a SECURITY CLASSIFICATION AUTHORITY | 3 DISTRIBUTION/AVAILABILITY OF REPORT<br>Approved for public release; distribution is unlimited. |
| 2b DECLASSIFICATION/DOWNGRADING SCHEDULE | |
| 4 PERFORMING ORGANIZATION REPORT NUMBER(S) | 5 MONITORING ORGANIZATION REPORT NUMBER(S) |
| 6a. NAME OF PERFORMING ORGANIZATION: Naval Postgraduate School<br>6b OFFICE SYMBOL (If applicable): Code 68 | 7a. NAME OF MONITORING ORGANIZATION: Naval Postgraduate School |
| 6c. ADDRESS (City, State, and ZIP Code)<br>Monterey, California 93943-5000 | 7b. ADDRESS (City, State, and ZIP Code)<br>Monterey, California 93943-5000 |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION<br>8b. OFFICE SYMBOL (If applicable) | 9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER |
| 8c ADDRESS (City, State, and ZIP Code) | 10 SOURCE OF FUNDING NUMBERS<br>PROGRAM ELEMENT NO · PROJECT NO · TASK NO · WORK UNIT ACCESSION NO |

11 TITLE (Include Security Classification)
BASE-LINE CALIBRATIONS OF THE MINI-RANGER III AND THE ROLE OF SIGNAL STRENGTH IN CORRECTING REAL-TIME HYDROGRAPHIC POSITION DATA

12 PERSONAL AUTHOR(S)
Hillard, Bruce F.

| 13a TYPE OF REPORT | 13b TIME COVERED | 14 DATE OF REPORT (Year, Month, Day) | 15 PAGE COUNT |
|---|---|---|---|
| Master's thesis | FROM ______ TO ______ | 1986 June | 151 |

16 SUPPLEMENTARY NOTATION

| 17 COSATI CODES | | | 18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number) |
|---|---|---|---|
| FIELD | GROUP | SUB-GROUP | Hydrographic Positioning; Mini-Ranger III; Hydrographic Survey; Signal Strength; Hydrography |

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Five base-line calibrations of the Motorola Mini-Ranger III (MRS III) shortwave positioning system were performed across Puget Sound, Washington, in January 1984. Two MRS III codes were calibrated over measured distances of 1061.2, 2417.5, 4083.1, 7016.8, and 9861.1 meters. Reference lengths were obtained to submeter accuracy using a Tellurometer, Model CA-1000.

Results of the data analysis suggest that an optimum base-line length of about 2,500 meters provides a characteristic calibration curve that adequately depicts all equipment configurations for a typical MRS III. The calibration curve was best characterized by high-gain antenna data for two Mini-Ranger codes. The high-gain antenna also exhibited the least sample deviation of the three antenna types calibrated. Range average was found to be insignificant. Regression curves applied to the data showed no change in quality of fit above a power of three and variances of 0.5 meters indicated a fair to good fit of the data.

| | |
|---|---|
| 20 DISTRIBUTION/AVAILABILITY OF ABSTRACT<br>☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS | 21 ABSTRACT SECURITY CLASSIFICATION<br>Unclassified |
| 22a NAME OF RESPONSIBLE INDIVIDUAL<br>Glen R. Schaefer | 22b TELEPHONE (Include Area Code): (408) 646-3131<br>22c OFFICE SYMBOL: Code 68Sc |

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

Approved for public release; distribution is unlimited.

# Base-Line Calibrations of the Mini-Ranger III and the Role of Signal Strength in Correcting Real-Time Hydrographic Position Data

by

Bruce F. Hillard
Lieutenant, National Oceanic and Atmospheric Administration
B.S., San Diego State University, 1976

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN HYDROGRAPHIC SCIENCES

from the

NAVAL POSTGRADUATE SCHOOL
June 1986

# ABSTRACT

Five base-line calibrations of the Motorola Mini-Ranger III (MRS III) shortwave positioning system were performed across Puget Sound, Washington, in January 1984. Two MRS III codes were calibrated over measured distances of 1061.2, 2417.5, 4083.1, 7016.8, and 9861.1 meters. Reference lengths were obtained to submeter accuracy using a Tellurometer, Model CA-1000.

Results of the data analysis suggest that an optimum base-line length of about 2,500 meters provides a characteristic calibration curve that adequately depicts all equipment configurations for a typical MRS III. The calibration curve was best characterized by high-gain antenna data for two Mini-Ranger codes. The high-gain antenna also exhibited the least sample deviation of the three antenna types calibrated. Range average was found to be insignificant. Regression curves applied to the data showed no change in quality of fit above a power of three and variances of 0.5 meters indicated a fair to good fit of the data.

TABLE OF CONTENTS


I. INTRODUCTION ....................................9

A. BACKGROUND INFORMATION ..........................9

1. SHF Positioning Systems .........................10

2. Theory of Operation .............................11

3. Field Uses of SHF Systems .......................12

4. MRS III Options .................................14

B. SYSTEM ERRORS ...................................14

1. Systematic Range Errors .........................14

2. Signal Strength as an Indicator .................19

C. NOS CALIBRATION PROCEDURES ......................21

1. Base-Line Calibrations ..........................21

2. Critical System Checks ..........................22

3. Noncritical System Checks .......................26

D. FOCUS OF RESEARCH ...............................28

1. The Future of SHF Units .........................28

2. Improving MRS III Calibration Methods ...........29

3. Present Calibration Problems ....................31

II. MINI-RANGER III POSITIONING SYSTEM .............33

A. SYSTEM COMPONENTS ...............................33

1. Receiver-Transmitter Assembly ...................33

2. Shore Reference Stations ........................35

3. Antennae ........................................36

4. Range Console ...................................41

B. MRS III SYSTEM OPTIONS ..........................43

1. Range Average ...................................43

2. Signal Strength Indicator .................. 44
III. EXPERIMENT DESIGN AND DATA REDUCTION .............. 47
A. OBJECTIVES ....................................... 47
B. ASSUMPTIONS ...................................... 47
C. DATA ACQUISITION AND PROCESSING ................. 48
1. Tellurometer Measurements .................... 48
2. Mini-Ranger Data Acquisition ................. 51
3. Mini-Ranger Data Processing .................. 52
4. Functional Curve Fitting ..................... 53
IV. OBSERVATIONS AND CONCLUSIONS ........................ 58
A. OBSERVATIONS ..................................... 58
1. Scatter Plots ................................ 58
2. Mean Range Error Plots ....................... 58
3. Range Error Versus Base-Line Distance Plots ............................... 59
4. Curve-Fitting Results ........................ 60
B. CONCLUSIONS ...................................... 64
C. RECOMMENDATIONS .................................. 66
APPENDIX A: MINI-RANGER III SYSTEM SPECIFICATIONS ...... 67
APPENDIX B: RANGE ERROR AND STATISTICAL PLOTS .......... 71
APPENDIX C: TELLUROMETER DATA .........................114
APPENDIX D: COMPUTER PROGRAMS .........................120
LIST OF REFERENCES ....................................147
INITIAL DISTRIBUTION LIST .............................148

LIST OF TABLES

I. ATTENTUATION ESTIMATES FOR A 3-CM WAVE LENGTH ..... 16

II. NOS CALIBRATION REJECTION LIMITS .................. 23

III. MINI-RANGER COMPONENTS AND SERIAL NUMBERS ......... 33

IV. BASE-LINE ENDPOINTS AND RESPECTIVE LENGTHS ........ 50

V. REGRESSION COEFFICIENTS ........................... 60

VI. COEFFICIENTS FOR CUBIC REGRESSION CURVES .......... 61

VII. COMPUTED VARIANCES FOR HIGHER DEGREE CURVES ....... 65

## LIST OF FIGURES


1.1 Typical NOS Base-Line Calibration Curve ............ 18

1.2 Pulse Shape Degradation and Range Errors ........... 20

2.1 RT Unit, Shore Stations, and Range Console ......... 34

2.2 Medium-Gain 13-db Sector Antenna ................... 37

2.3 High-Gain 19-db Sector Antenna ..................... 38

2.4 Omnidirectional 6-db Sector Antenna ................ 39

2.5 Medium-Gain Antenna Radiation Patterns ............. 40

2.6 Mini-Ranger III Range Console Assembly ............. 42

2.7 Signal Strength Indicator .......................... 45

3.1 Project Area and Station Locations ................. 49

3.2 Range Error versus Base-Line Distance, Code 0 ...... 54

3.3 Range Error versus Base-Line Distance, Code 1 ...... 55

4.1 Regression Curves for Code 0 ....................... 62

4.2 Regression Curves for Code 1 ....................... 63

ACKNOWLEDGEMENTS

The author thanks Ms. Pat Nyland, Mr. Denny Sutton, Mr. Rick Hastings, and the command and crew of NOAA Ship RAINIER. In addition, Mr. Russ Eastman of the Electronics Branch, Pacific Marine Center, provided valuable assistance during data acquisition. Capt. Glen Schaefer, thesis advisor, was a source of encouragement and assisted in editing. Lt. Cdr. Alan Anderson reviewed the thesis and offered many helpful suggestions. Photographs of the MRS III were provided by the Motorola Corporation. Mr. Brian P. Fields assisted by drafting figures.

# I. INTRODUCTION

## A. BACKGROUND INFORMATION

Electronic positioning of hydrographic survey vessels is a common practice in most automated hydrographic agencies. The National Ocean Service (NOS) is such an organization and is responsible for charting the United States territorial waters. The liability that accompanies this responsibility has prompted NOS to analyze the quality of its positioning data. Specifically, NOS would like to apply functionally-derived range error correctors to range rates obtained from superhigh frequency (SHF) positioning systems in real time. SHF positioning systems, such as Motorola's Mini-Ranger III (MRS III), are used for inshore and harbor surveys of scales greater than 1:20,000. Portability, accuracy, and automation are some of the reasons hydrographers prefer them.

The systems generally read out directly, in meters, the distance or range of the vessel. However, these range rates are not error free due to weather changes, attenuation distances, changing components in a given configuration, and other variables. The errors are determined through baseline calibrations where observed ranges are compared against a known distance and error curves are generated that display range error as a function of signal strength. Range correctors are then extracted from these curves and applied to the received range rates in near-real time.

In January 1984, calibrations were performed over five measured base lines that extended across Puget Sound, Washington. Three different antenna-types and three different Range Average settings were sampled for each base line. The results were used to explain the observed relationship between range error and signal strength over a variety of conditions and system configurations.

1. SHF Positioning Systems

SHF positioning systems have played a major role in the development of automated hydrography in NOS. In general, electronic methods have replaced antiquated manual methods for positioning on scales as large as 1:10,000. These microwave "black boxes" were for years rejected by stubborn "mossback" hydrographers who refused to accept the accuracy claims.

Today's electronic systems have freed the hydrographer of the tedium of manually acquiring and processing data so the hydrographer may concentrate on planning, error analysis, data interpretation, and other more important functions. MRS III has been a mainstay in west coast survey operations in NOS since the early 1970's.

Though most of the problems encountered with MRS III have been solved in the course of the agency's experience with the system, the problem of systematic range errors and their necessary correction has not been fully resolved. Additionally, a new automated hydrographic data acquisition

system called SDS III is slated to replace the present HYDROPLOT/HYDROLOG system in 1987. The SDS III development group is concerned about present SHF calibration methods and would like to devise a procedure for accurately determining range correctors over a variety of conditions and applying them in near-real time.

2. Theory of Operation

The theory of SHF positioning systems is an exchange of pulsed signals, where radar-like signals are transmitted from the vessel to an active shore station. Upon interrogation, the shore station returns a signal to the vessel. Distance is directly related to the round-trip travel time of the signal which is based on a fixed speed of propagation of the electromagnetic waves. Atmospheric effects will vary this speed of propagation but corrections can be applied given the proper meteorological data. [Ref. 1:pp. 45-52]

In the specialized case of the MRS III, the system uses one or more reference stations placed over points of known position on shore. Each reference station can transmit different pulse forms (called codes). These codes can be set in the reference stations and then selected for interrogation by setting a dial on the range console. The reference stations are actively interrogated by a receiver-transmitter assembly (RT unit) located aboard the vessel. The range console (also aboard the vessel) contains a stable counter clock that measures the travel time and converts it

to a distance. The range console also performs some internal smoothing and screening functions on the received signals. The resultant range rates are displayed at the front of the console. The system comes with three different types of antennae whose purposes are discussed in greater detail in Chapter II. The MRS III operates on a frequency of 5.4 to 5.6 GHz (versus 9 GHz for most SHF systems). This lower frequency helps reduce the possibility of interference from other radars in the working area. The system has been used by NOS for hydrographic surveys ranging from scales of 1:20,000 to as large as 1:5,000, when used in a hybrid mode such as range-azimuth.

3. Field Uses of SHF Systems

NOS has been using MRS III's for over a decade in a variety of survey applications. Most positioning schemes use the MRS III in either a range-range or range-azimuth geometry. Field edit positions, velocity casts, and bottom samples may also be positioned this way.

SHF systems are very portable and are well-suited for inshore hydrography and shoreline development requiring a shallow-draft vessel. Also, the positions of control stations in a project area can be verified by performing a system check calibration of the MRS III in the field. System checks are discussed in greater detail later in this chapter.

The systems are also used in NOS to check lane counts of medium-frequency positioning systems such as RAYDIST. In NOS, MRS III range rates are recorded at periodic intervals to explain or pinpoint where RAYDIST lane jumps (lane losses or gains) have occurred. Once lane jumps have been determined, whole lane correctors can be added to existing partial correctors of the RAYDIST to allow the hydrographer to continue survey operations. This procedure has saved considerable amounts of hydrographic data by relieving the hydrographer of the need to return to a calibration or initialization area.

SHF systems are practical for positioning a vessel using range-azimuth geometry. This geometry uses a shore-based observer with a theodolite positioned next to the SHF shore station. The observer radios observed azimuths to the survey launch. This setup is less probable with a medium-frequency system like RAYDIST because the observer's presence in the ground plane of the antenna affects the outgoing signal significantly. The popularity of range-azimuth geometry has prompted the recent development of automatic and semi-automatic total stations that consist of an SHF unit and electronic theodolite. Accuracy is increased by using an azimuth vice a second range rate in the position computation.

4. MRS III Options

There are several options that can greatly enhance the operation of the MRS III and help reduce the effect of systematic range errors:

a. A signal strength indicator displays the strength of each incoming signal. Signal strengths can be recorded in real time and used to identify position blunders or busts. They can also be used to determine range error correctors in near real time.

b. A range averaging option enables the user to select the number of range rates to be averaged before displaying. This option was originally installed to provide more accuracy by increased averaging of the data.

c. A multi-user capability offers 16 different codes. The extra codes give the hydrographer flexibility to work in areas where other Mini-Rangers are operating. Though not directly related to range errors, anomalous range rates can sometimes be attributed to other MRS III systems located in the survey.

d. A voltage cut-off switch powers the unit down when a minimum of 22 volts is not exceeded. It was found that voltages below 22 volts caused significant range errors.

e. The Space Diversity option solves the major problem of range holes or null zones by using two RT units. The nulling phenomenon is prevented by mounting two RT unit antennae at different heights on the survey vessel with a switch to select between the antennae, until an acceptable signal is received.

B. SYSTEM ERRORS

1. Systematic Range Errors

MRS III, though an accurate system (Appendix A) to use, still contains "some idiosyncracies that have remained largely unknown and which can lead to serious range error problems." [Ref. 2:p. 5] This statement was made in 1972.

Today many of the error sources have been resolved but others are as mysterious as ever. Operation of the system can be affected by range, meteorological conditions, range holes or null zones, antenna types, range averaging, power supply voltage, warm-up time, and even the RT unit cable length. Only errors due to range, range averaging, and antenna types were considered in evaluating the January 1984 calibration data.

Changes in weather within a survey project area can cause drift in the MRS III. Temperature changes directly affect a unit's circuitry--specifically its magnetron. "Very few weather phenomena directly or significantly affect the range measurement of the Mini-Ranger system because of the high frequency of operation--5 GHz. However, meteorological conditions do contribute to variations of the effective path length (apparent range) and, more severely, atmospheric absorption (attenuation)." [Ref. 3:Section 3.1.2]

The actual propagation speed of the radio frequency (RF) waves is a function of wavelength, air temperature, barometric pressure, and vapor pressure. The counter clock inside the range console uses a fixed, average value for the propagation speed. Deviations from the fixed value are determined during a base-line calibration performed in the field by the user.

Phenomena of "high particle density such as rain, mist, fog, or photochemical smog" are also responsible for

attenuation. A formula (Eqn. 1.1) exists for calculating the attenuation due to rain [Ref. 4:p. 11] where A is attenuation in db, r is rainfall rate in mm/hour, and a & b are tabulated frequency functions.

$$A = ar^{b} \tag{1.1}$$

Signal attenuation reduces the range of operation and lowers signal strengths, so calibrations should be performed as near to the working area as possible to minimize errors due to weather. Thus, any range errors found during the base-line calibration will be a function of weather conditions in the project area. Table I shows attenuation estimates derived by using Equation 1.1.

TABLE I

ATTENUATION ESTIMATES FOR A 3-CM WAVE LENGTH

| Precipitation Rate (mm/hr) | Attenuation (db/km) |
|---|---|
| 6.0 | 0.192 |
| 15.2 | 0.613 |
| 18.7 | 0.728 |
| 22.6 | 0.801 |
| 34.3 | 1.280 |
| 43.1 | 1.640 |

Systematic range errors are the focus for this thesis. Their presence is attributed to the fundamental radar equation (Eqn. 1.2), where P' is the intensity of radiated power, P is the peak power, G is the antenna gain, and R is the distance from the source.

$$P' = PG/R^2 \tag{1.2}$$

The effects of the radar equation are shown by plotting range error versus distance in kilometers. The same curve form is also found in plots of range error versus signal strength. In the latter case, the errors result from artificially-attenuated signals that simulate greater distances. Thus, NOS base-line calibrations of the MRS III are related to the radar equation. In a typical NOS calibration curve (Fig. 1.1), the range error curve becomes exponential below a certain critical signal strength threshold. At high signal strengths the curve exhibits a near linear form. Casey refers to the threshold value separating the two curve types as the Critical Strength Threshold (CST). NOS calls the CST the Minimum Acceptable Signal Strength (MASS) and NOS rejects data below this value. Casey has found that above the CST "the errors are distributed with a Gaussian or normal distribution; below the CST the distribution is log normal." [Ref. 2:p. 9]

The important point is if the curve were considered "well-defined" below the MASS, data acquired with signal strengths below this threshold might not be rejected. This amounts to a large savings in time and money when viewed from a (NOS) fleet aspect. A well-defined curve is one whose data exhibit low standard deviations.

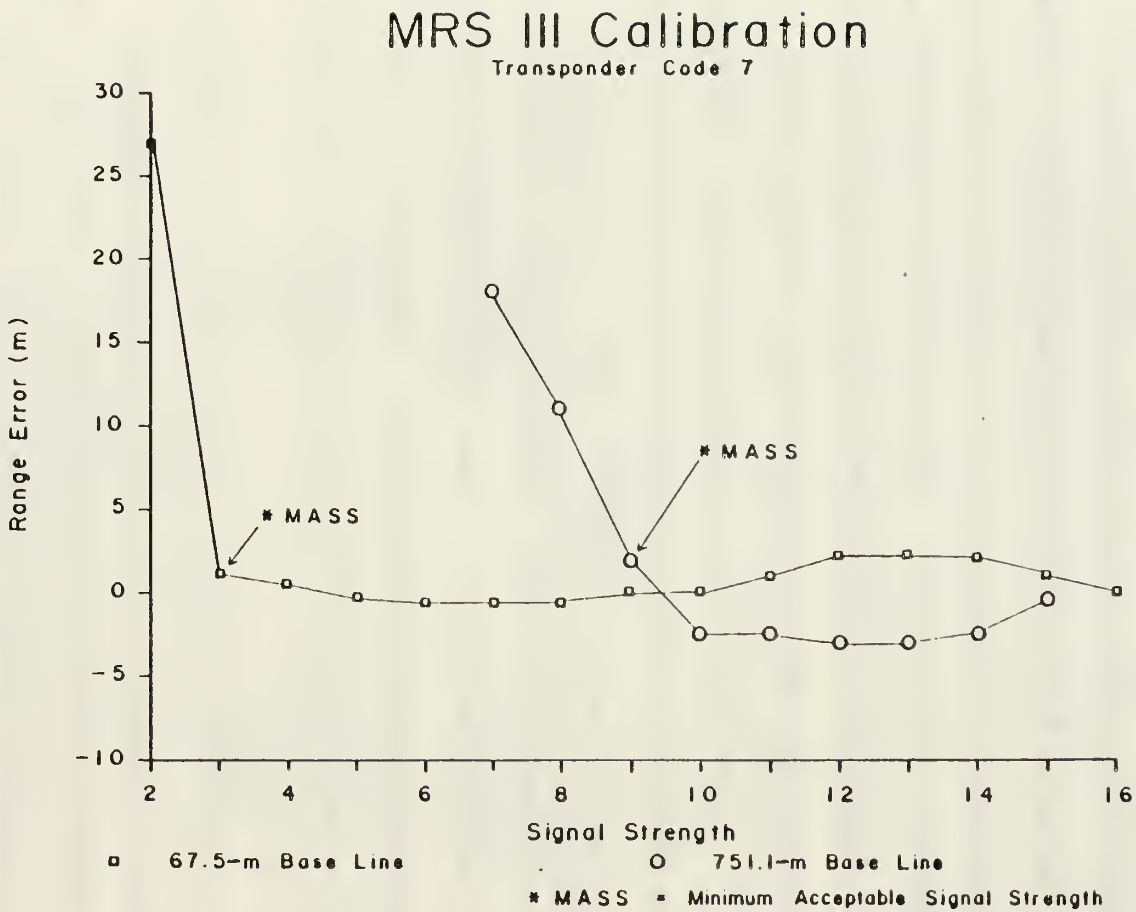



Figure 1.1 Typical NOS Base-Line Calibration Curve

Range errors are due principally to pulse shape degradation of the received signals. To determine the amount of degradation and the effect on the received range rate, a signal strength integer value is used that defines, through calibration, what range corrector (the algebraic inverse of range error) should be applied to the range rate.

2. Signal Strength as an Indicator

NOS MRS III's are equipped with the optional signal strength indicator that displays a "relative number output that is directly proportional to the amplitude of the received signal from the reference station." [Ref. 3:Section 5.2.3] Signal strengths are measured because tests have shown that range error is dependent on signal strength in a repeatable manner. Signal strengths are significant because the counter clock, which measures the elapsed time, must recognize the leading edge of the received pulse because ". . . the leading edge shape of the incoming pulse varies with the amplitude so that a low amplitude (read signal strength) leads to a systematic timing (read range) error." [Ref. 4:p. 9] This relationship between elapsed counter time and amplitude is best shown by diagram (Fig. 1.2).

The factors affecting MRS III signal strength that are discussed in this thesis are range averaging, base-line lengths, and three types of reference station antennae.

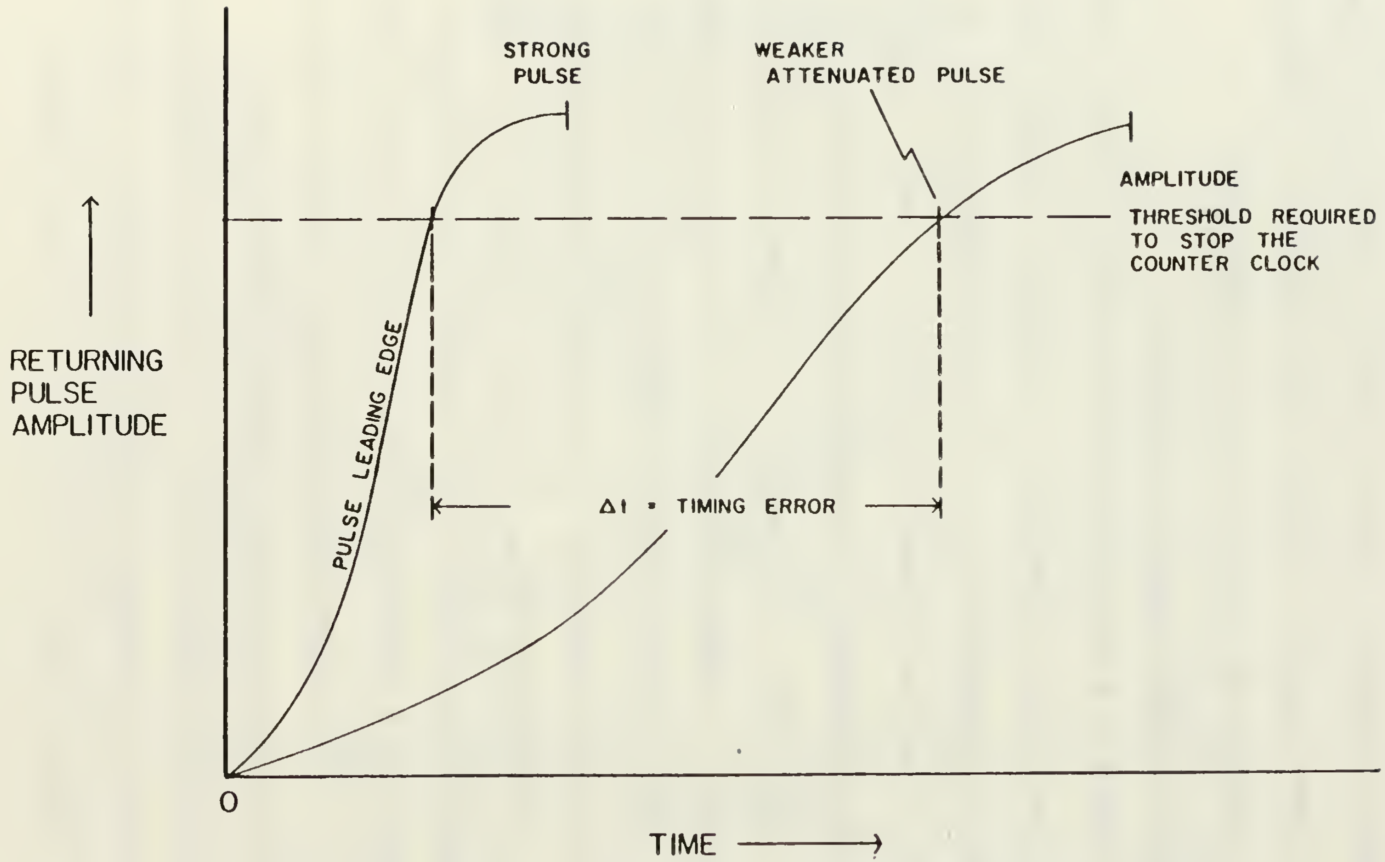



Figure 1.2 Pulse Shape Degradation and Range Errors

## C. NOS CALIBRATION PROCEDURES

### 1. Base-Line Calibrations

Base-line calibrations are required by NOS (1) at the beginning and end of a survey project, (2) at intervals not exceeding 2 months during long projects, (3) whenever an RF component is changed in either an RT unit or transponder, and (4) whenever the difference between prior base-line correctors and daily system check correctors exceeds specified rejection limits. [Ref. 5:p. M-2]

A description of the base-line calibration procedures is taken from the PMC OPORDER, Appendix M:

> The base-line calibration is performed by introducing signal attenuation with a variable attenuator over a known distance. The observed range readings are compared to the known distance at various signal strengths to determine range errors. A graph is constructed which typically shows a nearly-linear portion followed by a sharp rise at low signal strength values. A mean error is determined for signal strength values corresponding to the nearly-linear portion of the graph and its algebraic inverse is the corrector to be applied to the observed range readings. The signal strength value corresponding to the sharp upswing portion of the curve is the minimum value allowed for hydrographic survey operations. [Ref. 5:pp. M-2 & M-3]

For a base-line calibration, ten range rates are sampled for each signal strength to obtain the mean range. Base-line lengths are measured prior to calibration to submeter accuracy using an NOS-approved laser or microwave electronic distance measuring instrument.

NOS presently requires the length of the base line to be between 700 and 3,000 meters. The optimum length has yet to be determined and is discussed in the thesis.

Though the correctors determined from a base-line calibration are most often those applied to the final position data, NOS does require that a closing or bracketing calibration be performed at the completion of a survey. Additionally, daily critical or noncritical system checks are made to monitor any drift in the Mini-Rangers. These system checks test for instrument drift and verify or dispute the most recent base-line correctors.

2. Critical System Checks

A critical system check is defined as one in which an independent method of position determination is employed to check range errors. Noncritical system checks are much less time consuming and are performed in conjunction with a recent critical system check. This approach was devised by NOS to minimize the calibration time and maximize the time spent acquiring hydrographic data. Though noncritical system checks require less time, they do not provide an independent check fix to verify the first fix. Whenever the difference between a daily system check and base-line calibration corrector exceeds the rejection limits (Table II) and cannot be resolved after a careful check is made, a new base-line calibration is required to continue hydrographic survey operations. [Ref. 5:pp. M-5 & M-6]

The following are methods currently approved for critical system checks.

TABLE II

NOS CALIBRATION REJECTION LIMITS

| Survey Scale | Rejection Limit (m) |
|---|---|
| 1: 5,000 | 3 |
| 1: 10,000 | 5 |
| 1: 20,000 and smaller | 10 |

a. Fixed-Point Method

The fixed-point method is the critical system check method preferred by NOS. It involves bringing the launch alongside a geodetically-positioned pile, wharf, rock, or other point feature and comparing the observed range rates with precomputed range rates. It is operationally and computationally simplest of all the methods and is not restricted by visibility in the work area. However, the method is not always feasible as frequently a point feature is not available in the work area. Additionally, this method is restricted to launches since deep-drafted survey ships cannot afford the grounding risk of the shoal waters surrounding such features.

b. Navigational Range and Cut-Off Angle Method

The navigational range and a cut-off angle method can be employed when as few as two geodetic control stations are in the area. To construct a navigational range, one geodetic control station is used as a front (or rear) range marker. A second station, or erected signal, is used as the other range marker.

While the survey vessel is moving along the established navigational range, the angle measured by sextant between the front (or rear) range marker and the second geodetic control station is the cut-off angle that marks the vessel's position when the cut-off angle agrees with any of a number of preselected angles. The preselected angles and known navigational range azimuth facilitate the precomputation of vessel positions. Knowing the vessel position and the geodetic position of the MRS III shore stations, predicted range rates are computed for each cut-off angle for comparison with the observed range rates.

c. Range-Azimuth Method

The range-azimuth method can produce rapid results when a total station (a theodolite and electronic distance measuring instrument) is used to acquire the azimuth and range to the launch from a geodetic control station. Given the necessary onboard computer program, a single shore observer radios azimuth and range data to the launch. The computed position is converted to a set of predetermined MRS III range rates that are compared with the observed rates. This method is the most accurate available and quickest after the preferred fixed-point method.

d. Intersection of Two Navigational Ranges Method

The intersection of two navigational ranges method can be accomplished with a minimum of four control points. A navigation range is constructed as described in

the above method (b). Though this may require considerable set-up time, the method is quick and convenient once the ranges are in place. To calibrate, the launch steers one range and crosses the other. The observed range rates are compared with precomputed rates by subtraction.

e. Three-Point Sextant Resection Method

The three-point sextant resection method has been used extensively in NOS pending the development of more efficient methods. It requires a minimum of four visual targets and three sextant observers. Simultaneous to the reading of the MRS III range rates, horizontal sextant angles are observed to the four signals. The observed sextant angles are input into a calibration program. Though computations are performed by an onboard computer, they are still tedious and more involved than the simpler subtractions used in some other methods.

f. Theodolite Intersection

The theodolite intersection method requires three observers, each with a theodolite to turn angles from an initial station to the survey launch. The recorded azimuths define a fix and check fix that are input into a calibration program. Although it is one of the more accurate methods, it is rarely used by NOS personnel due to the equipment and labor demands. The ensuring computations are only slightly faster than for the resection method.

### 3. Noncritical System Checks

Noncritical system checks are generally quicker than critical system checks but do not include an independent position determination. Additionally, they cannot check geodetic control in the working area. NOS has approved their use because the MRS III has been used in west coast survey operations for over a decade and has developed into a reliable system that usually does not develop flaws which cannot be detected using noncritical system checks in conjunction with periodic critical system checks. This fact, coupled with the policy of using base-line correctors in lieu of separate correctors determined daily, has been the driving force behind reducing the requirements for twice-daily critical system checks. [Ref. 5:p. S-2]

#### a. Three-Range Method

The three-range method checks the operation of three separate shore stations by comparing the three possible fixes generated by the three range rates. A major constraint is that the vessel be positioned to obtain a near 60-degree angle of intersection for each of the three lines of position (LOPs) to obtain consistently strong fixes for each pair. Unlike the other two noncritical system check methods that utilize ready-made calibration forms, the three-range method requires separate fix computations and an onboard computer. The key to using this method is realizing that it is sensitive to the intersection angles of the LOPs.

b. Base-Line Crossing Method

The base-line crossing method compares a sum of two observed range rates to the known base-line length connecting two transponder stations. Thus, the launch crosses between two shore stations and a mark is called when a shore observer radios that the crossing launch is on range with the two shore stations. To stabilize the update rate of the MRS III, the launch steers a range arc of one of the stations. The ensuing computations are subtractive and simple to perform.

c. Launch to Launch Method

The launch to launch method is very quick because many launches can be checked at once. Using a critically-checked launch, designated the guide launch, other launches come alongside with their bows pointed at the transponder to be checked. They do not have to be tied but they should be aligned along their beams. MRS III rates are simultaneously recorded and the guide launch correctors applied. Non-guide launches then apply their respective base-line correctors and compare to the rejection limits table (Table II). All system check methods, both critical and noncritical, require the hydrographer to first apply the most recent base-line correctors to the observed rates before comparing them against their known values.

## D. FOCUS OF RESEARCH

### 1. The Future of SHF Units

SHF positioning systems have been available for over a decade. They may eventually be replaced by futuristic satellite systems such as the NAVSTAR Global Positioning System (GPS). The need to locate transponders on shore for launch operations could be eliminated along with the sometimes complex geodetic networks that support a survey. With only 6 of the scheduled 18 satellites in orbit, testing has already begun to determine GPS accuracies. The entire system is expected to be operational in 1987. Other advantages to this powerful system are its continuous passive output, multiple user capabilities, and world-wide coverage. It will also free the hydrographer from any constraints due to fix geometry or line-of-sight. Studies have been conducted by the Naval Oceanographic Office (NAVOCEANO) in Bay St. Louis, Mississippi, to determine GPS's suitability for dynamic positioning of a survey launch. Thus far, GPS accuracies of 10 meters have been observed in a dynamic mode. [Ref. 6:p. 4]

A cost study recently done by NAVOCEANO [Ref. 7:p. 84] states a savings of nearly four million dollars a year for two Navy hydrographic survey ships would be a result of using GPS. It appears likely that the GPS system will make dinosaurs of not only SHF positioning systems, but medium-frequency systems as well. If GPS receivers were made

affordable even to fishermen, it would replace LORAN-C and Omega. However, there are several reasons why the present systems will still be used:

> GPS accuracies for hydrography (a dynamic mode) are not yet verified. This fact alone suggests that SHF systems will continue to be used in NOS for large-scale hydrography.
>
> GPS may not be able to keep pace with the short fix interval used to obtain hydrographic positions on large-scale surveys. Also, additional computer storage may be necessary to accomodate the large amounts of GPS data.
>
> Access to the precise (P) code may be restricted to military operations. Since NOS does not directly support such operations, it may not be granted access to this code. Access to the P code also generates considerable security problems regarding its use by NOS personnel. If access to the P code is limited there are other techniques, such as interferometry and differential GPS, that will improve the accuracy of data obtained with the coarse acquisition (CA) code.
>
> The initial cost for a GPS receiver is prohibitive to the average mariner and may also be too expensive for NOS. "Initial estimates of costs are $50,000 for each system (excluding the cost of the receivers) and $15,000 to $30,000 one-time cost for tailored software." [Ref. 7:p. 83] Using this estimated, one can imagine the initial cost to NOS for nearly 50 operating systems.

### 2. Improving MRS III Calibration Methods

The above statements suggest that MRS III and similar systems will still be used during the evolution and testing of SDS III. Base-line calibrations, to determine systematic range errors, will still be necessary. The present base-line calibration methods can be automated and enhanced to acquire more data in less time without manual manipulation by the observer. One such practice is to record calibration data

directly into a portable computer. The same program used to acquire the data, for example LOTUS 1-2-3, can be used to automatically average the correctors and graph them. NOAA Ship DAVIDSON is presently using this procedure for base-line calibrations of its Mini-Ranger Falcon 484, the MRS III successor. Possible refinements to the method include a mathematical, nonsubjective, determination of the MASS and applying curve-fitting routines to obtain a functional form of the calibration curve.

A further enhancement would be to tabulate the correctors into a corrector file such as the Sound Velocity, Tide, Zone, Parameter, and Station Tables that exist presently in the Bathymetric Swath Survey System (BSSS). Another possibility is to incorporate the functional form (equation) of the calibration curve directly into the start-up routine of the SURVEY or HYDROPLOT acquisition programs by entering the equation's coefficients. This could easily be implemented by prompting the operator for the equation's coefficients. The creation of a more automated method for base-line calibrations could provide a corrector curve and/or tape for direct application to the acquired navigation data. Automation of the current base-line calibration procedures and the ensuing computations that yield the calibration curve would enable the operator to sample more calibration data in the same amount of time.

3. Present Calibration Problems

Some issues need to be addressed regarding present NOS methods of determining range error correctors for corresponding signal strengths:

The assumption of a best-fit linear curve being most representative of an MRS III's range error-signal strength relationship is not necessarily the most accurate one considering the variety of conditions and equipment configurations over which a system can operate. Another choice is to use a separate corrector for each signal strength in the calibration curve. This approach assumes that a functional relationship exists between range error and signal strength and can be defined through curve-fitting procedures. This thesis discusses what degree polynomial best fits the January 1984 data after curve-fitting techniques were tried.

The optimum base-line length for a base-line calibration has been revised several times by NOS. As new field phenomena are realized the recommended calibration length changes [Ref. 8]. When base lines as short as 100 meters are used, corrector anomalies occur at the higher signal strengths. The converse situation of observing range anomalies at low strengths for longer base lines limits the base-line length on the high end. The cause of the anomalies at close-in ranges is "the measured pulse amplitude riding on top of the previously decaying pulse." [Ref. 8] Anomalies occur at ranges less than 700 meters where long distances are being simulated with a variable attenuator. The dilemma is if too short a base-line length is selected, the resultant signal strength versus range corrector curve may not become exponential at low signal strengths and thus MASS cannot be determined. On the other hand, if too long a base-line length is selected, no correctors will be obtained at higher signal strengths and correctors for field data must be extrapolated from lower signal strength correctors [Ref. 9:p. 2].

At present in NOS, MASS is a subjective estimate of the point of inflection (or signal strength) where the curve becomes exponential. A mathematical definition of MASS that can be used in future calibration software is desirable. Although the aim is

to fit a continuous function to the calibration curve, the curve is really not a discrete one in that non-integer signal strengths do not exist. In the case of the newer Falcon system, every signal strength may not be calibrated due to the expanded signal strength scale. The curve is thus empirically derived from those strengths that were calibrated. The MRS III signal strength scale is from 0 to about 25, while the Falcon scale range is from 0 to 100.

Present base-line calibration procedures are not responsive to observed anomalies in the calibration curve because a single mean corrector is selected for the entire curve. By using a functional form of the entire curve, anomalies could either be rejected through an outlier statistical test or become incorporated into the correction process. The presence of these anomalies is confirmed by data obtained for this thesis. Anomalies are shown in the range-error versus signal-strength plots in Appendix B.

This research should aid NOS in developing a calibration procedure that realistically predicts the range corrector for an observed range rate given the range and signal strength over a variety of system configurations.

## II. MINI-RANGER III POSITIONING SYSTEM

### A. SYSTEM COMPONENTS

A good understanding of the components of the MRS III (Table III) and their operation will be helpful to the reader.

TABLE III

MINI-RANGER COMPONENTS AND SERIAL NUMBERS

| System Component | Serial Number |
|---|---|
| Range Console | (RA-4), B0269 |
| RT Unit | (RA-5), B1108 |
| Signal Strength Counter No. 1 | 110 |
| Signal Strength Counter No. 2 | 111 |
| Transponder Code 0 | C1789 |
| Transponder Code 1 | C1883 |

#### 1. Receiver-Transmitter Assembly

The term universal station refers to the assembly that houses either an RT unit or a reference station (Fig. 2.1). A universal station contains a motherboard, power supply, modulator, and the RF assembly. An RT unit is a universal station with a video interface assembly and a 6-db antenna. The receiver-transmitter assembly (RT unit) consists of a radar transmitter, a radar receiver, and a video interface assembly. Due to the complexity of the electronics, technical descriptions of the system's components and their operation are taken directly from the MRS III Positioning System Maintenance Manual.

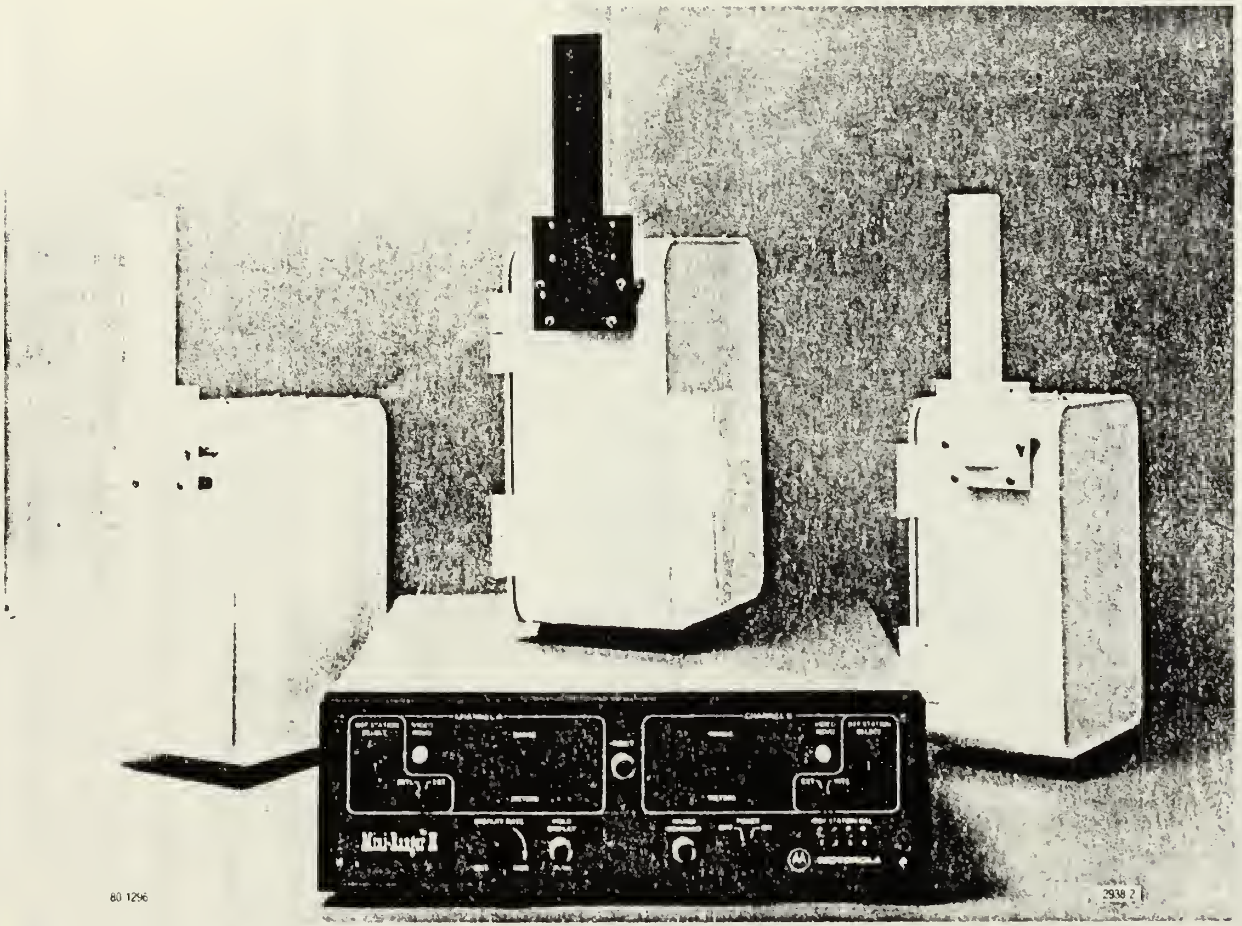



Figure 2.1  RT Unit, Shore Stations, and Range Console

The encoded pulse modulation signal from the range console passes through the video interface assembly to the transmitter. The resulting coded RF signal passes through the circulator to the antenna. At the same time, the transmitter causes a video signal to pass through the video interface assembly to the range console where it becomes a start signal for the range counters. Meanwhile, the interrogation signal is received, processed, and a reply is generated by the selected reference station assembly. The reply signal is received by the RT unit antenna and is passed through the circulator to the receiver. The resulting video then passes through the video interface assembly and the interconnect cable to the decoder assembly in the range console. There it is decoded and becomes the stop signal for the range counters. The receiver-transmitter operates from a +28 and -12 volt DC supply provided by the range console. The receive and transmit frequencies are factory preset to standard frequencies. [Ref. 10:p. 7]

### 2. Shore Reference Stations

An RT unit is located on the survey launch and interrogates one or more reference stations located ashore. A reference station is a shore-based universal station that is located over a known geodetic control station.

A reference station contains a 16-code decoder assembly and a 13-db antenna. The description of a reference station's operation is helpful in understanding possible error sources. An interrogation signal from the RT unit is coupled through the reference station receiver to the 16-code decoder assembly. If the proper first-to-second pulse and second-to-third pulse spacing is detected, the decoder will respond with a two-pulse signal that is coupled to the modulator, causing a reply to be transmitted back to the RT unit. The first-to-second pulse spacing is given in microseconds and corresponds to a given code value. The

second-to-third pulse spacing is either 50 or 54 microseconds. A reference station must be set to the code that has been selected on the range console.

3. Antennae

There are three different types of antennae for use with the MRS III (Figs. 2.2, 2.3, and 2.4). The antennae are classified by their purpose which is related to the output gain and radiation pattern characteristics. Elevation and azimuth patterns refer to the vertical and horizontal radiation angles of an antenna (Fig. 2.5).

The medium-gain antenna (Fig. 2.2) has a gain of 13 db and is the antenna most often used for hydrographic survey operations and base-line calibrations. The horizontal azimuth pattern of the medium-gain antenna is 80 degrees and its vertical elevation pattern is 15 degrees.

The high-gain antenna (Fig. 2.3) has a gain of 19 db and offers the user a greater operating range. The high-gain antenna has a vertical pattern of only 5 degrees. The narrower vertical pattern focuses the radiated energy to increase the operating range of a shore station. The leveling of a high-gain antenna is more critical then, due to its narrower vertical pattern.

The omnidirectional antenna (Fig. 2.4) has a gain of 6 db and is used on the survey vessel with the RT unit. It can also be used on shore reference stations located on islands or prominent headlands where 360-degree azimuth

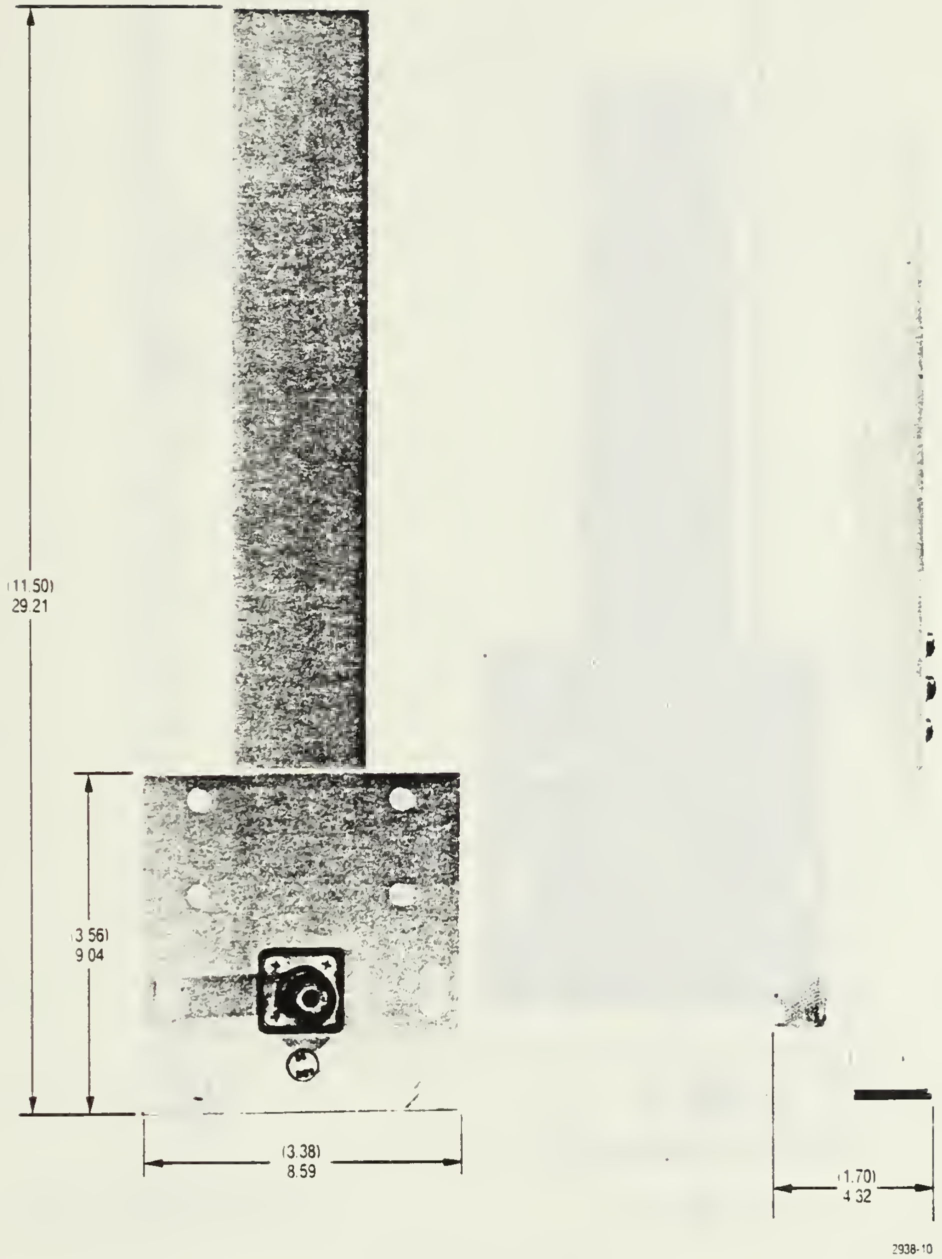



Figure 2.2 Medium-Gain 13-db Sector Antenna

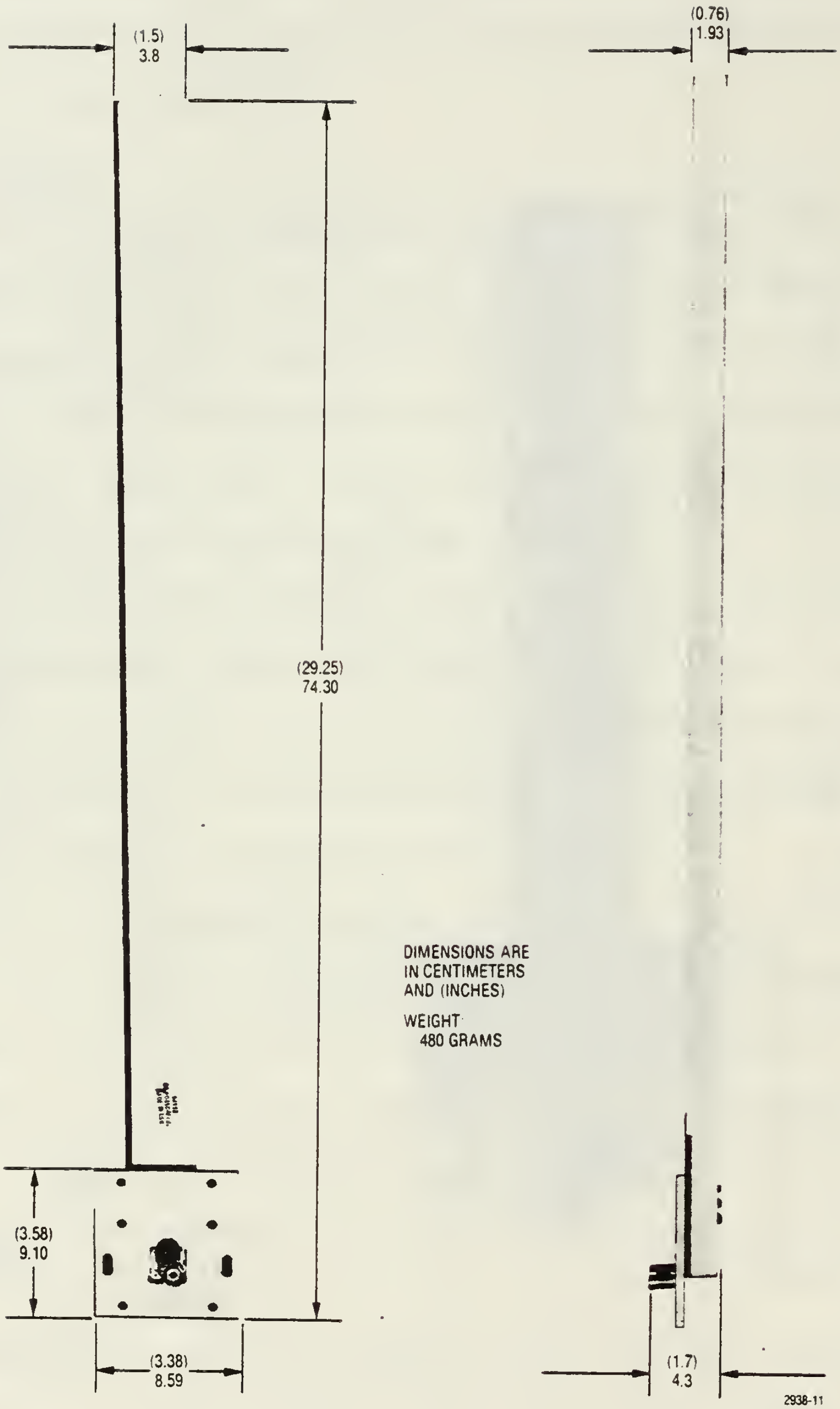



Figure 2.3 High-Gain 19-db Sector Antenna

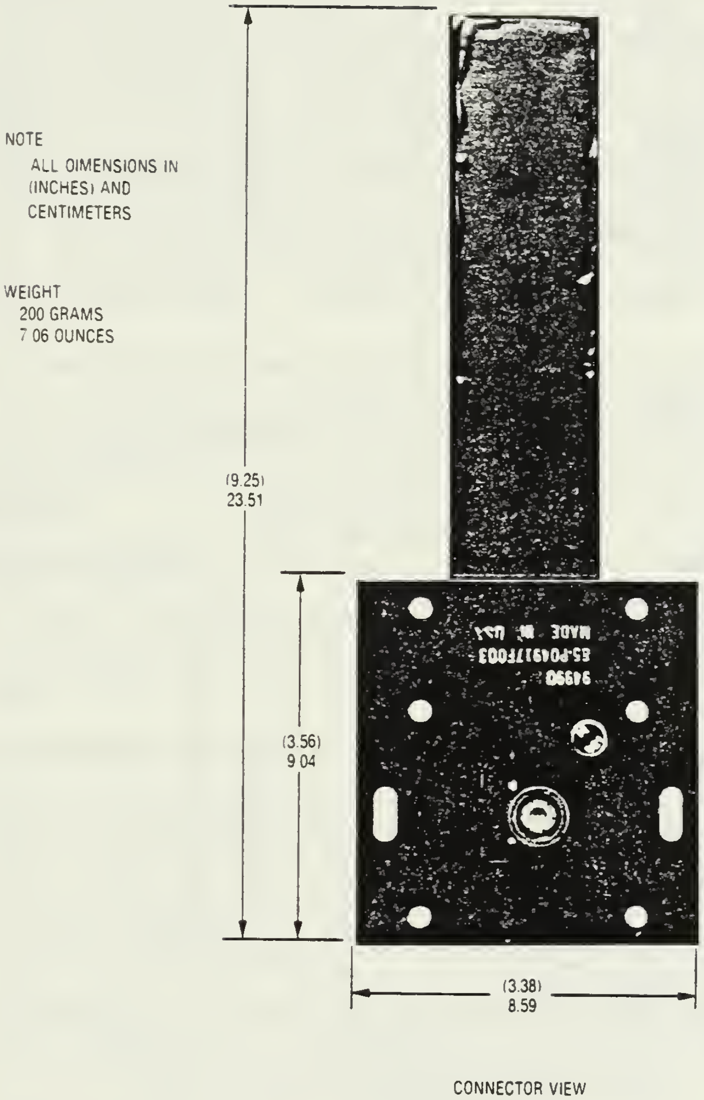



Figure 2.4 Omnidirectional 6-db Sector Antenna

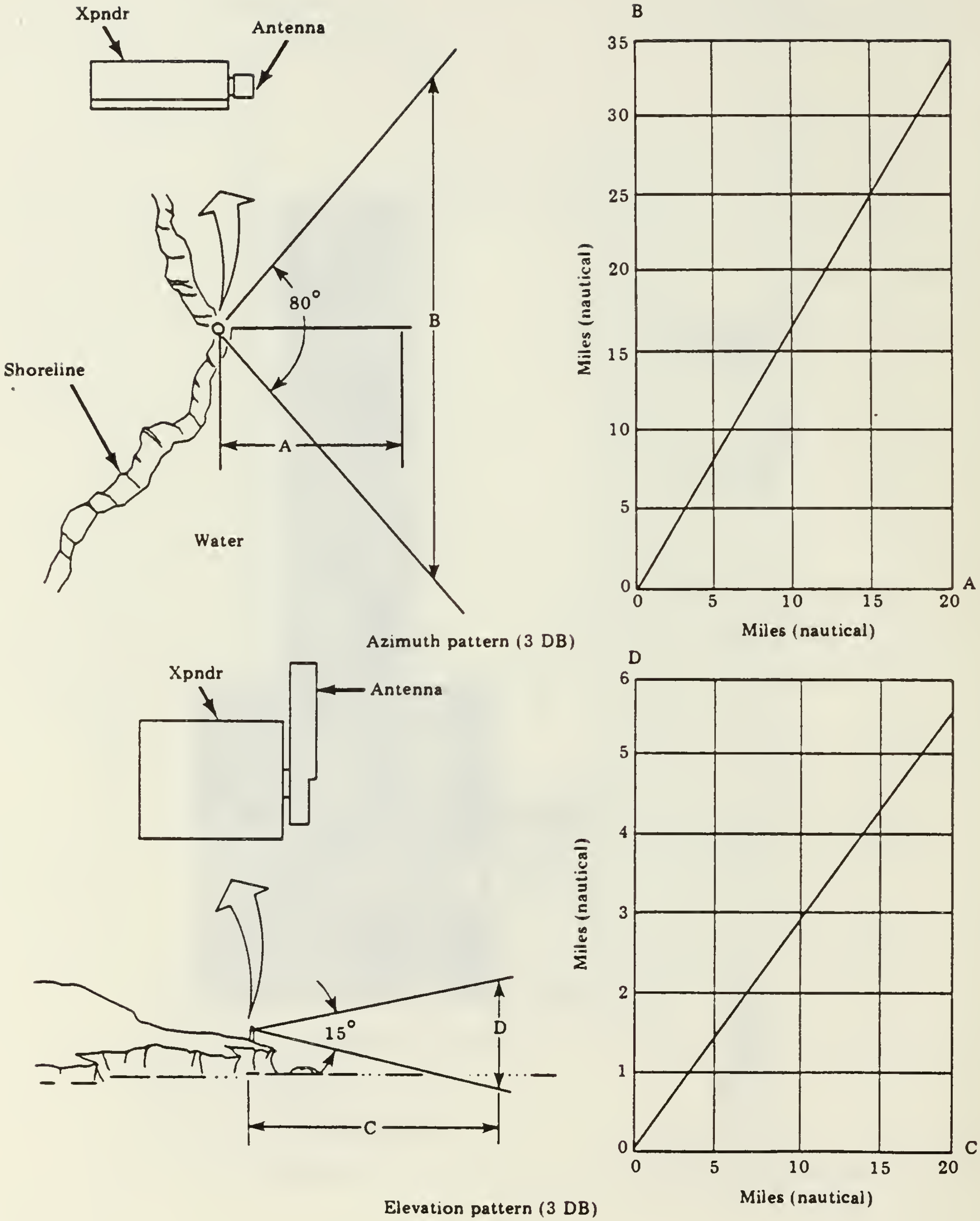



Figure 2.5 Medium-Gain Antenna Radiation Patterns

coverage is desired. The vertical pattern is 15 degrees. An interesting fact about this type of antenna is its misleading name. "An omni antenna will receive signals from all directions. . . . The catch, however, is that it does not receive equally well from all directions. The omni antenna has a preferred direction." [Ref. 2:p. 8]

Previous research has shown that the 90/270-degree directions are the preferred ones. Unfortunately, the antenna is usually installed with the 0/180-degree axis pointing toward the work area. [Ref. 10:p. 8] The January 1984 calibrations were performed using the omnidirectional antenna with the 0/180-degree direction pointing toward the other antennae.

4. Range Console

The range console (Fig. 2.6) consists of a coder assembly, range control assembly, range counter display assembly, motherboard assembly, and a power supply assembly. The power supply assembly provides operating voltages for both the range console and the RT unit. A description of the operation of the range console follows. The coder assembly generates the transmitter pulse modulation signal. When a start signal is received from the receiver-transmitter assembly, the range counter starts to count. The reference station assembly reply video is decoded by the decoder and becomes the stop signal for the range counter. After five consecutive reference station assembly replies, the range

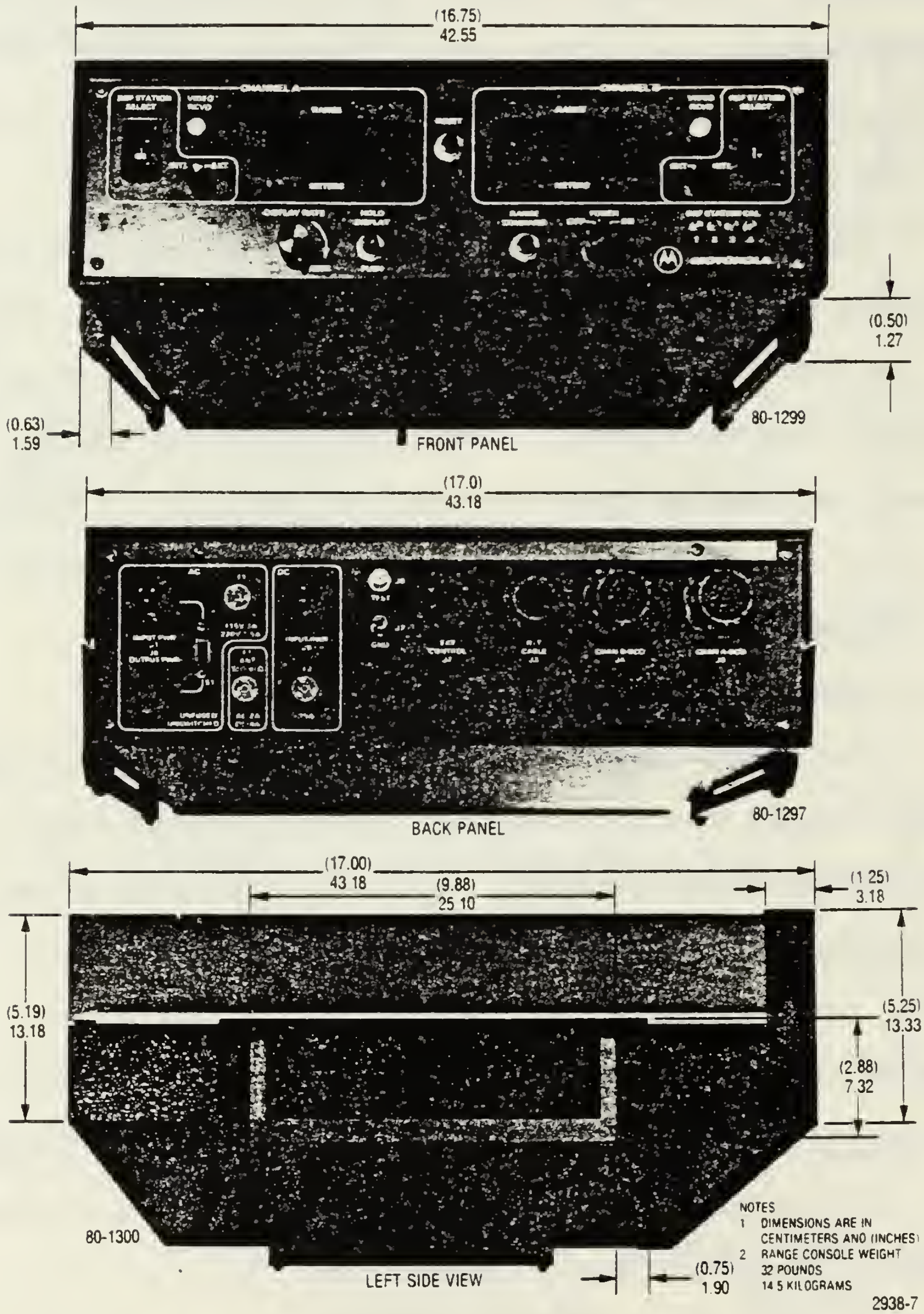



Figure 2.6 Mini-Ranger III Range Console Assembly

counter control commands the front panel range counter display to refresh the range readout. The read information, in parallel binary-coded decimal (BCD) format, also is available at a rear panel connector for use by peripheral equipment such as printers or computers. The range console interrogates each of the two reference station assemblies alternately. Two thumbwheel switches on the front panel select two reference stations by code. Four distinct reference station assembly codes may be used, two at a time, in a standard MRS III. An option to this allows selection from any of 16 codes, rather than four, to improve the versatility of the system should other users be present in the work area.

## B. MRS III SYSTEM OPTIONS

### 1. Range Average

An optional feature of the range console included in all NOS MRS III's is the range average switch. The range average switch performs internal averaging of the received range rates at one of five accuracy levels. This option helps the system produce more repeatable readings.

A range average switch is located on the front panel of the console that is labeled in total turn-around cycles called PRF cycles. The five settings are 1, 5, 20, 40, and 75. "In the OFF position, the range console will take the normal 5 consecutive PRF cycles to produce one valid range reading. In the 75 position, the console takes 75 PRF cycles or 15 samples to automatically provide an average.

This is the same as the operator taking 15 readings from the front indicators and calculating the average. If the range console misses one reading in acquiring the average, the entire group of readings is not thrown out, only that group of 5 in which the average was missed." [Ref. 3:Section 5.2.2]

Accuracy claims (by Motorola) for the MRS III are based on a one-sigma standard deviation or probability of 68.23 percent (Appendix A). The best results are obtained by using a single survey vessel and the 75 range average setting. "If more than one range console is used in the system, some erratic readings will result if the RANGE AVG switch is set above 20." [Ref. 3:Section 3.1.4] Higher settings require more update time. This is important if multiple users need to share shore stations. To determine whether range averaging is significant during a base-line calibration of a system, the January 1984 calibration data were acquired using settings of 20, 40, and 75.

2. Signal Strength Indicator

The signal strength indicator is mounted atop the range console (Fig. 2.7). The ranges shown on the console correspond to signal strength values displayed on the indicator. A brief explanation of the counter will aid the reader in understanding the range error/signal strength relationship.

The video processor inside the RT unit converts the received pulse amplitude to a standard amplitude proportional

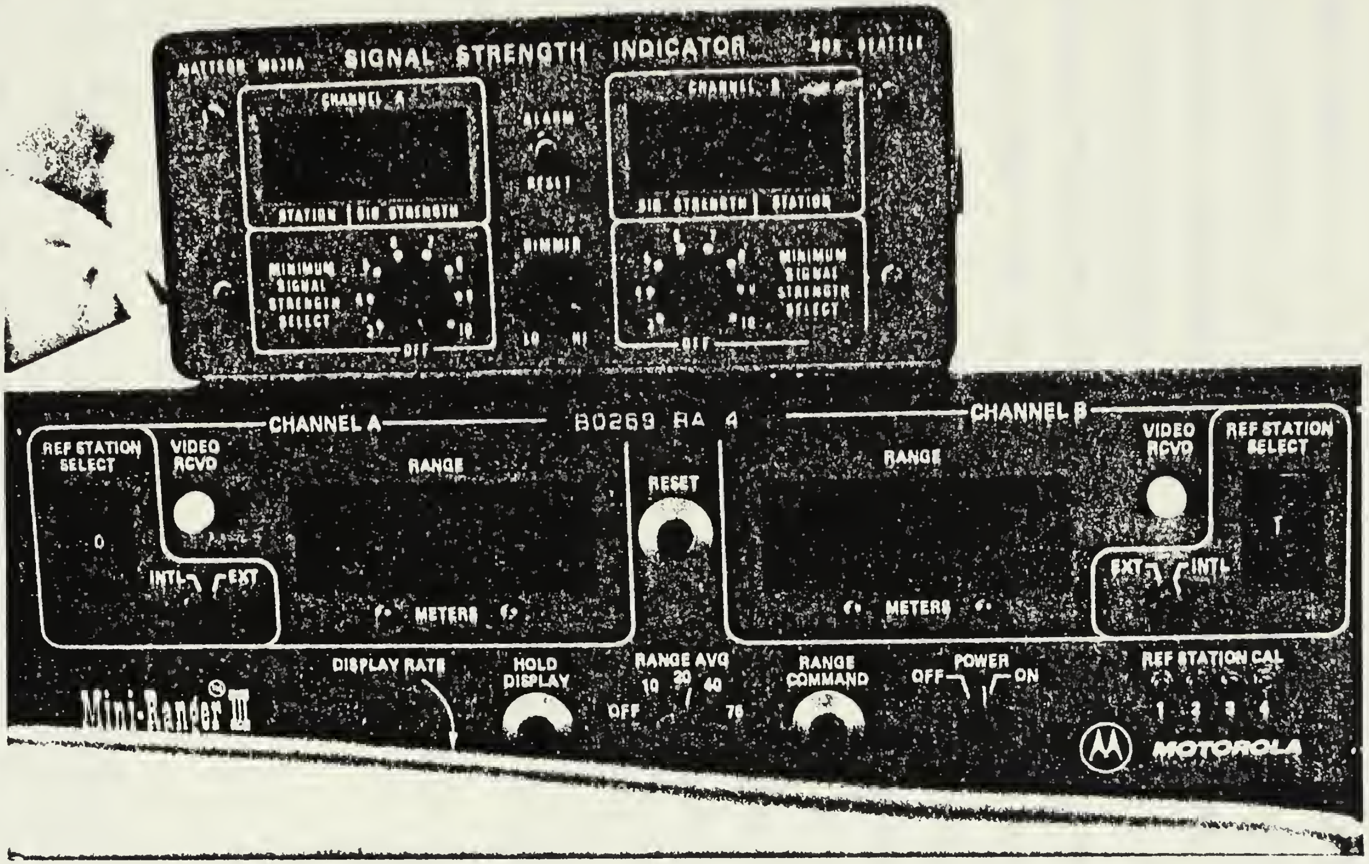



Figure 2.7 Signal Strength Indicator

to the amplitude of the received pulse. This pulse is then used to start and stop a counter clock that generates a relative strength value in integer form [Ref. 3:Section 5.2.3].

Typically the signal strength will vary from 4 to 25 for the MRS III. NOS counters are also equipped with audio alarms that are activated when signal strengths fall below a preset value. When the range console receives a signal that has undergone attenuation, it's degraded amplitude is converted to a relative value, displayed on the indicator.

Signal strengths can be used with the alarm option to identify weak areas of coverage. NOS signal strengths are recorded directly on the data tape. The next step is to use these recorded signal strengths to extract a range-error corrector in near-real time.

# III. EXPERIMENT DESIGN AND DATA REDUCTION

## A. OBJECTIVES

The main objective of this thesis is to generate an MRS III corrector curve that, when given a range rate and corresponding signal strength as input, will yield an accurate range corrector that can be applied to the range rate in near-real time. The corrector curve should be characteristic of all possible MRS III equipment configurations and console settings. To obtain such a curve, the thesis addresses several related topics:

Range Average was examined for its significance in defining the calibration curve.

The significance of the three different types of antennae on the base-line calibration was investigated.

The significance of base-line distance was investigated in hopes of finding an optimum base-line calibration length.

An equipment configuration that is most characteristic for an MRS III unit was identified.

## B. ASSUMPTIONS

Several assumptions were made when performing the field work and analyzing the data:

Range errors were not related to power supply voltages since the units furnished by RAINIER were equipped with "cut-off" switches that deactivate the transponders when the voltage is less than 22 volts. Therefore, errors due to power fluctuations were assumed negligible.

The horizontal and vertical pointings of the reference station antennae were considered to be negligible since each code/reference station was pointed in the same

manner. The antennae were pointed visually for the three shorter base lines. For the two longer base lines, a radio was used to tell the reference station operator when optimum signal strengths were observed.

The tellurometers that were used to measure the base lines were accurate to plus or minus 0.015 meters. Thus, the lines were measured to submeter accuracy so reference distances introduced no significant error into the data.

Artificially attenuating the incoming signals to the RT unit adequately represented real conditions encountered in the field. Though this assumption is not necessarily valid, the artificial attenuator offers the only practical means of simulating the attenuation caused by signals traveling long distances.

Internal drift of the MRS III's during the calibrations was assumed to be negligible. Each day a warm-up time of 30 minutes was observed before the first calibration. Throughout the day, the units were not powered down and antenna changes were affected by momentarily halting the interrogation process with the "Hold Display" button on the front of the range console. Morning warm-up times were within the prescribed time as recommended in the NOS Operation and Installation Manual. Thus, range errors due to temperature changes within the magnetron of the MRS III system were also considered insignificant since ambient temperatures during the January calibration were invariably within two to three degrees. [Ref. 3]

## C. DATA ACQUISITION AND PROCESSING

The calibration field work for the thesis was performed January 27 to 30, 1984, across Puget Sound and Shilshole Bay, Washington (Fig. 3.1). Base-line calibrations were performed over five different distances using the station at West Point Lighthouse as a pivot point (Table IV).

### 1. Tellurometer Measurements

Prior to beginning the actual static calibrations, each base line was measured to submeter accuracy using a

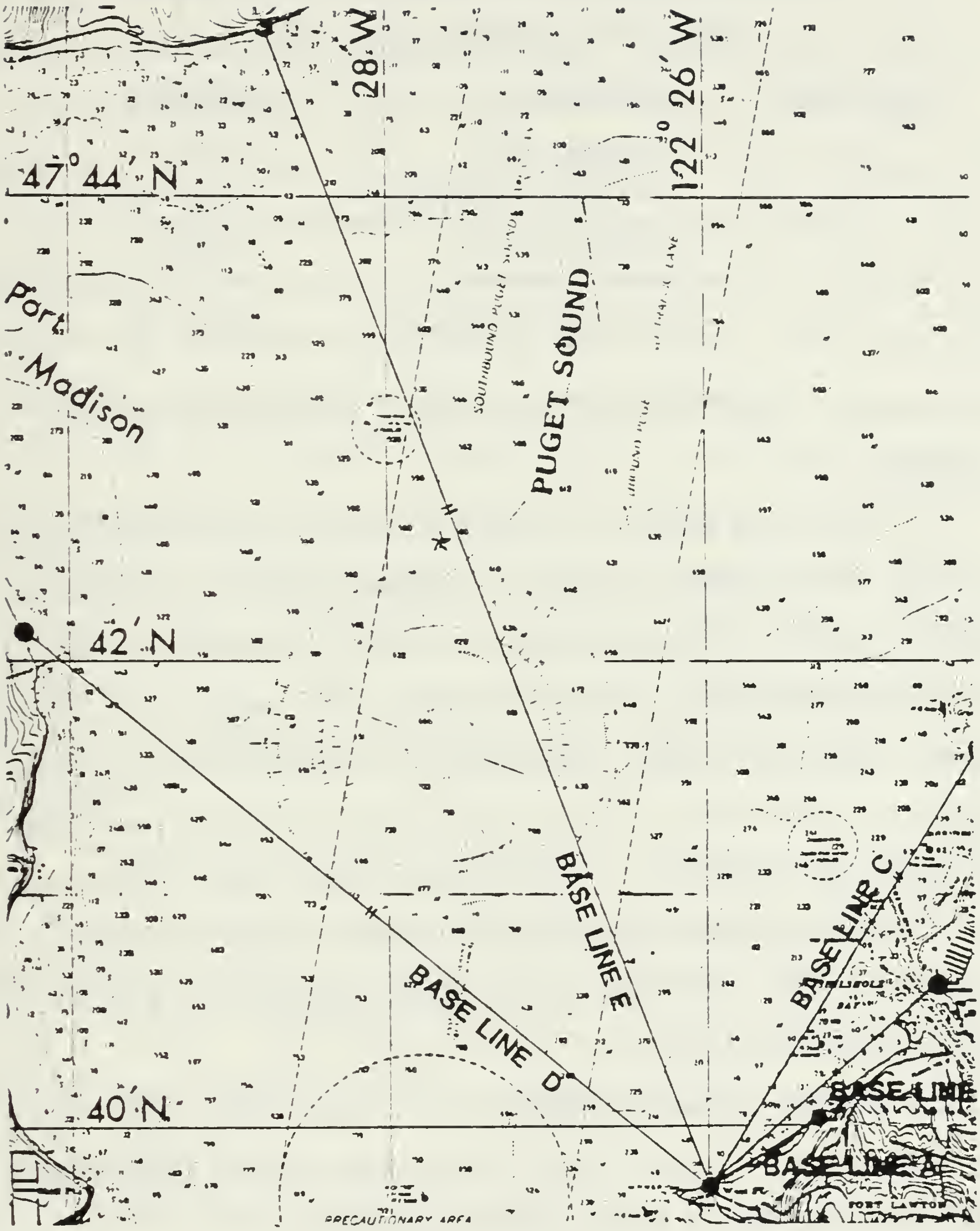



Figure 3.1 Project Area and Station Locations

TABLE IV

BASE-LINE ENDPOINTS AND RESPECTIVE LENGTHS

(From West Point Lighthouse)

| Base Line | End Point | Length(m) |
|---|---|---|
| A | Sewage Gate | 1061.17 |
| B | Shilshole Marina | 2417.48 |
| C | Meadow Point | 4083.10 |
| D | Point Monroe | 7016.77 |
| E | Point Jefferson | 9861.08 |

Tellurometer model CA-1000 electronic distance measuring instrument.

Since the MRS III range rates were slope distances, no slope to horizontal distance computations were necessary. However, due to the tellurometers having a preset value for the refractive index in air of radio waves equal to 1.000325, weather data were taken concurrently to correct this fixed value for variations in wet- and dry-bulb temperatures and for barometric pressure. These same weather data were input into a Hewlett-Packard 9815S calculator. Meteorological correctors were performed using an NOS geodetic program (EDM-03/821201, option A).

The Tellurometer observation forms (NOAA Form 76-61A) for the five base lines include the output tape generated by the HP 9815S calculator (Appendix C ).

These submeter results were used as reference distances for the five base lines and subsequently in the determination of average range errors to 0.1 meter.

### 2. Mini-Ranger Data Acquisition

Base-line calibration procedures are documented in the PMC OPORDER [Ref. 5:Sections M-3 through M-5]. The range console and two signal strength counters were placed in the rear opening of the rental hatchback to shield the recorder from strong winds. Two reference stations were set to codes 1 and 0, respectively, and were positioned at the designated endpoint (Table IV) where an operator aligned and pointed the reference stations at the station near West Point Lighthouse and changed antennae when requested.

For each signal strength setting, ten range rates were recorded. The RT unit was artifically attenuated and the resulting range recorded for each corresponding signal strength. After calibrating a code for three range average settings--20, 40, and 75--the medium-gain antenna was removed and replaced with a high-gain or omnidirectional antenna.

All three antenna types were calibrated for each of two codes at three range average settings for each of five base lines. The total number of calibration "sets" was 3 x 5 x 3 x 2 = 90. The beginning time of each individual calibration was recorded and was included in the header record for each data file.

The range console displays A and B show independent rates. This allows the observer to sample two independent rates at once. For each calibration set, ten readings were obtained by pressing the "Hold Display" button five times.

The ten readings were used to compute the mean range error for each signal strength.

3. Mini-Ranger Data Processing

Data from the January 1984 calibrations were manually logged into data files on the Naval Postgraduate School's IBM 3033 computer. Ten readings per signal strength were recorded for each code (codes 0 and 1). Each data file contained a header record that identified the base line, code, range average setting, antenna type, and time of calibration.

The data were printed in a readable form and checked for correctness. The data were also corrected for a systematic offset of 16 meters that was not adjusted or zeroed. Instead of adjusting the console, the 16-meter offset was applied to all the data.

After verifying the correctness of the data, a FORTRAN/DISSPLA [Ref. 11] computer program STAT (Appendix D) computed mean rates, mean range errors, and variances for both codes.

A "calibration set" is herein defined as a distinct set of signal strengths and corresponding range errors for a specific configuration of code (0 or 1), antenna type, range average setting, and base line.

Program SSPLOT (Appendix D) plotted mean range error versus signal strength and standard deviation for each mean error (Appendix B). Standard deviation is displayed as a vertical bar for its respective range error.

Plots of range error versus signal strength were generated to assess the significance of range average and antenna type to the overall calibration curve for each code. Program SCATTER (Appendix D) generated scatter diagrams (Appendix B) of mean range errors for each of the two codes.

Program WALK (Appendix D) generated plots of mean range error versus base-line distance using signal strengths as markers. These plots (Figs. 3.2 and 3.3) show that lower signal strengths consistently separate themselves from the others.

4. Functional Curve Fitting

Curve fitting is a technique that employs a least squares criterion to determine unique regression curve of any degree up to a n minus 1, where n is the number of paired data points. The fitted curve is a functional form or equation from which range correctors can be predicted in real time. SDS III would be capable of referencing electronic correctors by two methods. One method uses a table of stored data points in an array; it is the simplest but would require some type of interpolation for intermediate signal strengths. A second method uses the functional form of the calibration curve to extract range errors for a given signal strength.

The main advantages of the functional approach are the simplicity of computer computations and the accounting

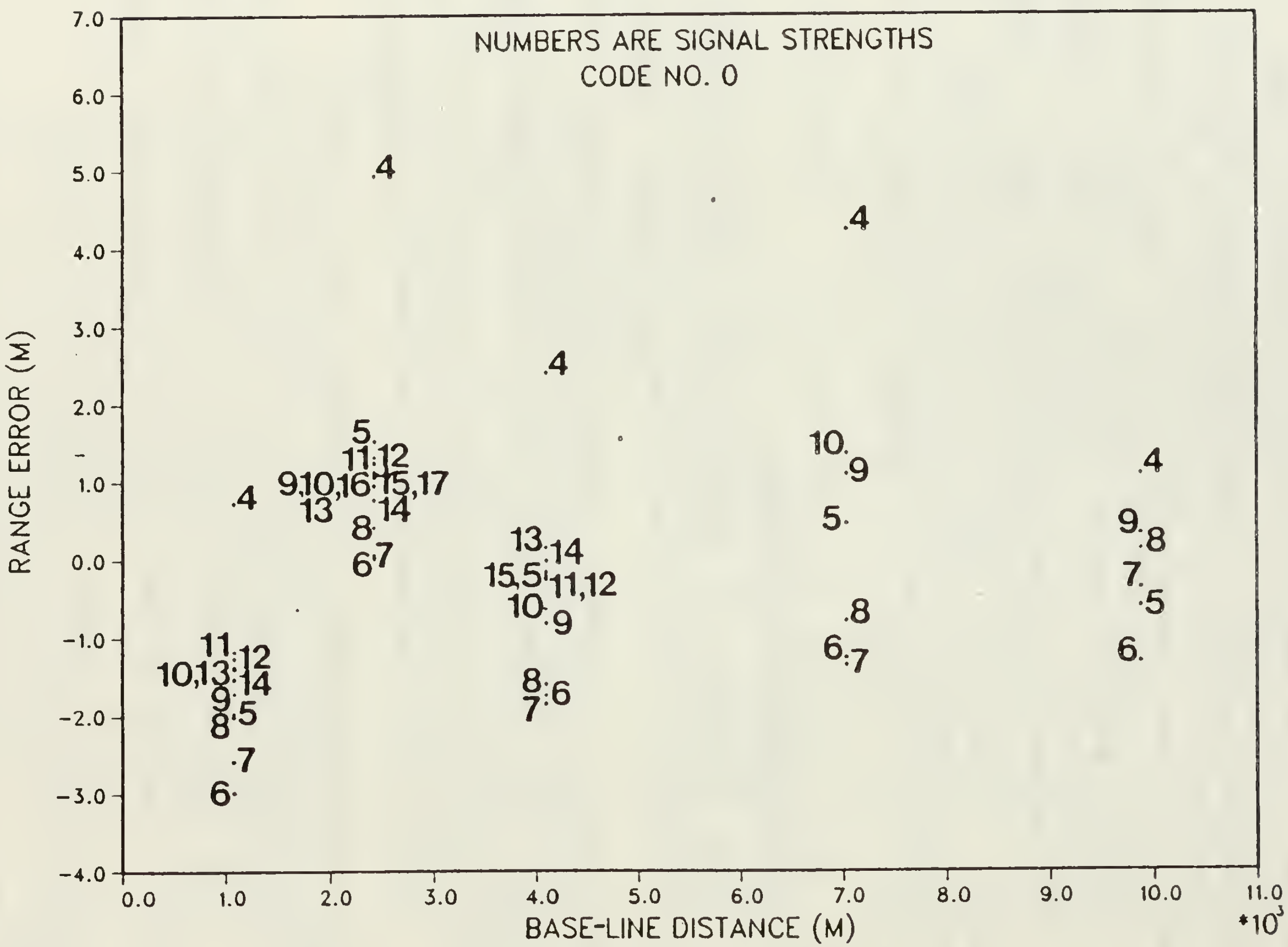



Figure 3.2 Range Error versus Base-Line Distance, Code 0

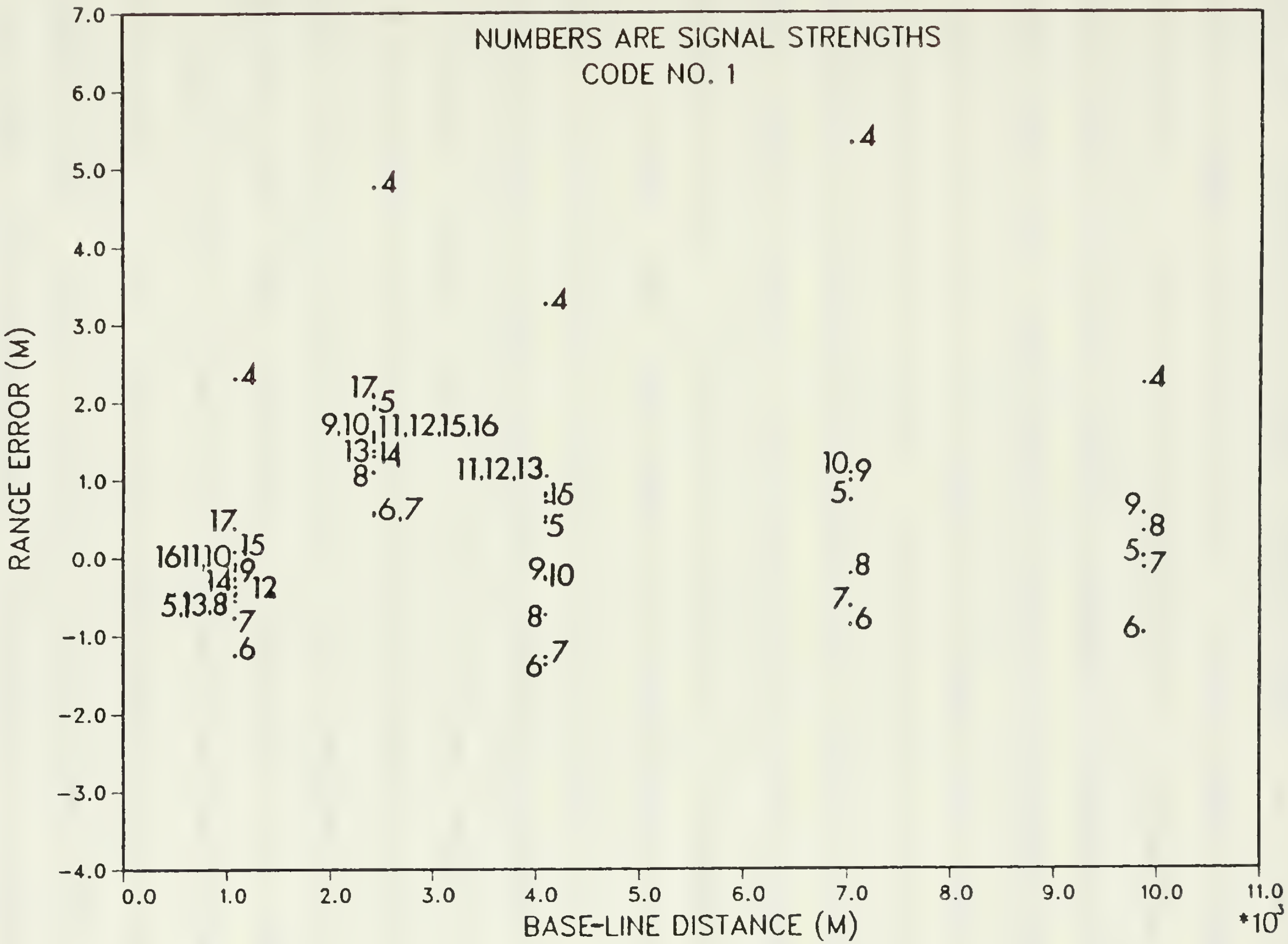



Figure 3.3 Range Error versus Base-Line Distance, Code 1

for intermediate signal strengths in a nonlinear, more accurate manner. The major reason to limit the time spent calibrating electronic control systems is to maximize data acquisition time. NOS's desire is to minimize the calibration time by using faster, noncritical daily system checks. If the calibration procedures were automated, a greater number of data could be sampled and several base lines or equipment configurations could be investigated. The time saved by letting a mini-computer compute the statistics and regression curves directly from a floppy disk containing the raw calibration data would enable the operator to obtain more calibration data in much less time. A curve-fitting program POLY (Appendix D), obtained from Gerald's book on numerical analysis, was applied to the data [Ref. 12:p. 492].

The Gerald program computes coefficients for up to a seventh-degree polynomial regression curve, though only fifth-degree and lower were attempted on the January calibration data. Both the beta function (variance) and the graphical presentation suggest that a third-degree fit was the highest polynomial fit obtainable. Graphs were made that show regression curves for powers of one through three along with the actual mean range errors that were used to produce the coefficients defining the regression curves. These graphs are discussed in Chapter 4. Since program POLY does not print the regression coefficients, a Hewlett-Packard 41C statistical program (SIGMAPOLYC) was used to compute the

coefficients for a cubic regression curve for each base line for the two codes. All data and programs used in the thesis have been recorded on 9-track magnetic tape.

# IV. OBSERVATIONS AND CONCLUSIONS

## A. OBSERVATIONS

### 1. Scatter Plots

Scatter plots (Appendix B) show range error versus signal strength for each calibration set. By inspection, base lines D and E contributed very little to the scatter plot for both codes. Range error differences of up to 9 meters were observed at the two lowest signal strengths. Base line B exhibited the least sample deviation and covered the greatest range of signal strengths. Though fewer data points were available for the two longer base lines D and E, the general shapes of these curves were similar to the three shorter base lines.

Data anomalies occurred for base line D code 0 (Appendix B) between signal strengths five and eight. A maximum difference of 5 meters was observed between the high-gain antenna curves and the other two antenna types. The agreement between the three antenna types was typically 1 to 3 meters and is best seen on the mean range error plots.

### 2. Mean Range Error Plots

Mean range error plots showed differences in mean range error due to the range average setting were not significant across base lines or antenna types. A visual

inspection of the data showed excellent agreement between different range average settings.

High-gain antenna data showed the least sample deviation in a consistent manner. This fact and the great range of signal strengths over which one can calibrate suggest that calibrating with the high-gain antenna produces a calibration curve representative of all three antenna types. An anomaly in the high-gain antenna data occurred in base line A (around 1,000 meters) for code 0 (Appendix B). The plot shows an upward shift of the curve to range errors of 3 to 5 meters higher than the data from the other antennae. The same behavior was not observed with code 1. Inspection of the mean range error versus base-line distance plots (Figs. 3.2 and 3.3) point to a MASS of signal strength five for all the plots.

3. <u>Range Error Versus Base-Line Distance Plots</u>

The range error versus base-line distance plots (Figs. 3.2 and 3.3) show a dip where range error decreased when signal strength increased from four to six and then increased for signal strengths seven and above. This characteristic dip near signal strengths four and five was noted for all equipment configurations and distances. Signal strength four was separated from the remaining signal strengths by a constant positive value of 3 to 4 meters for each base line. The other range errors (with signal strength markers) were grouped close together. The

characteristic dip mentioned above was not as pronounced on the fitted regression curves--especially the cubic fit.

As anomaly occurs on the base line B range error versus base-line distance plot. Base line B was partially obstructed by a pier 200 yards forward of the West Point endpoint. The above mentioned range errors may have been the result of additional attenuation from the pier.

4. Curve-Fitting Results

Regression coefficients were computed for degrees one through four (Table V). Variance was also computed in the program for each degree of fitted polynomial and was used as a numerical indicator of a curve's "goodness of fit" (Table VI). The regression curves were plotted (Figs. 4.1 and

TABLE V

REGRESSION COEFFICIENTS

$$(y = a + bx + cx^2 + dx^3 + ex^4)$$

| Degree of Polynomial | Variance | Coefficients a | b | c | d | e |
|---|---|---|---|---|---|---|
| Code 0: | | | | | | |
| 1 | | -0.88 | 0.88 | 0.00 | 0.00 | 0.00 |
| 2 | | 4.54 | -1.13 | 0.06 | 0.00 | 0.00 |
| 3 | | 17.38 | -5.66 | 0.53 | -0.02 | 0.00 |
| 4 | | 17.34 | -5.66 | 0.53 | -0.02 | 0.00 |
| Code 1: | | | | | | |
| 1 | | 0.82 | -0.02 | 0.00 | 0.00 | 0.00 |
| 2 | | 3.85 | -0.70 | 0.03 | 0.00 | 0.00 |
| 3 | | 13.34 | -4.06 | 0.38 | -0.01 | 0.00 |
| 4 | | 13.34 | -4.06 | 0.38 | -0.01 | 0.00 |

TABLE VI

COEFFICIENTS FOR CUBIC REGRESSION CURVES

$(y = a + bx + cx^2 + dx^3)$

| Base Line | VARIANCE | a | b | c | d |
|---|---|---|---|---|---|
| Code 0: | | | | | |
| A | 0.53 | 18.56 | -7.47 | 0.84 | -0.03 |
| B | 0.64 | 18.14 | -5.36 | 0.51 | -0.02 |
| C | 0.69 | 22.02 | -7.86 | 0.82 | -0.03 |
| D | 0.55 | 53.44 | -21.08 | 2.60 | -0.10 |
| E | 0.73 | 34.55 | -15.82 | 2.27 | -0.10 |
| Code 1: | | | | | |
| A | 0.33 | 9.11 | -2.94 | 0.28 | -0.01 |
| B | 0.52 | 15.01 | -4.22 | 0.40 | -0.01 |
| C | 0.73 | 25.49 | -8.97 | 0.95 | -0.03 |
| D | 0.88 | 66.84 | -27.09 | 3.51 | -0.15 |
| E | 0.80 | 42.67 | -18.77 | 2.63 | -0.12 |

4.2) with the mean range error/signal strength pairs used as input for creating each higher degree fit. Gerald's book [Ref. 12:p. 437], describes the variance as an indicator for deciding what degree of polynomial should be used. As higher degree polynomials are used, the deviations of the points from the fitted curve will decrease until, when the degree of the polynomial n equals n minus 1, there is an exact match (assuming no duplicate data at the same x-value). Variances for the four higher polynomial regression curves indicated that the cubic fit was the best. One

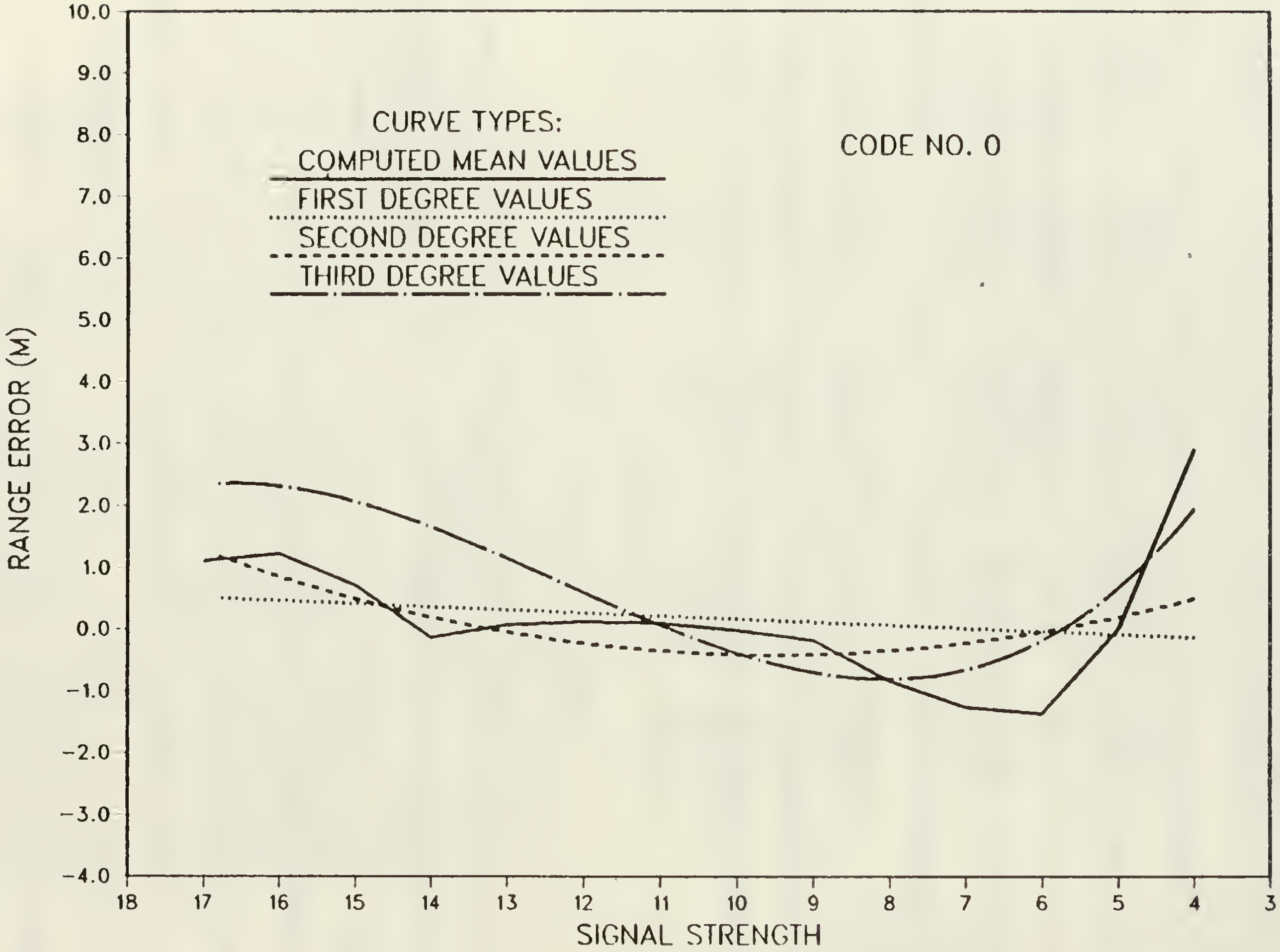



Figure 4.1 Regression Curves for Code 0

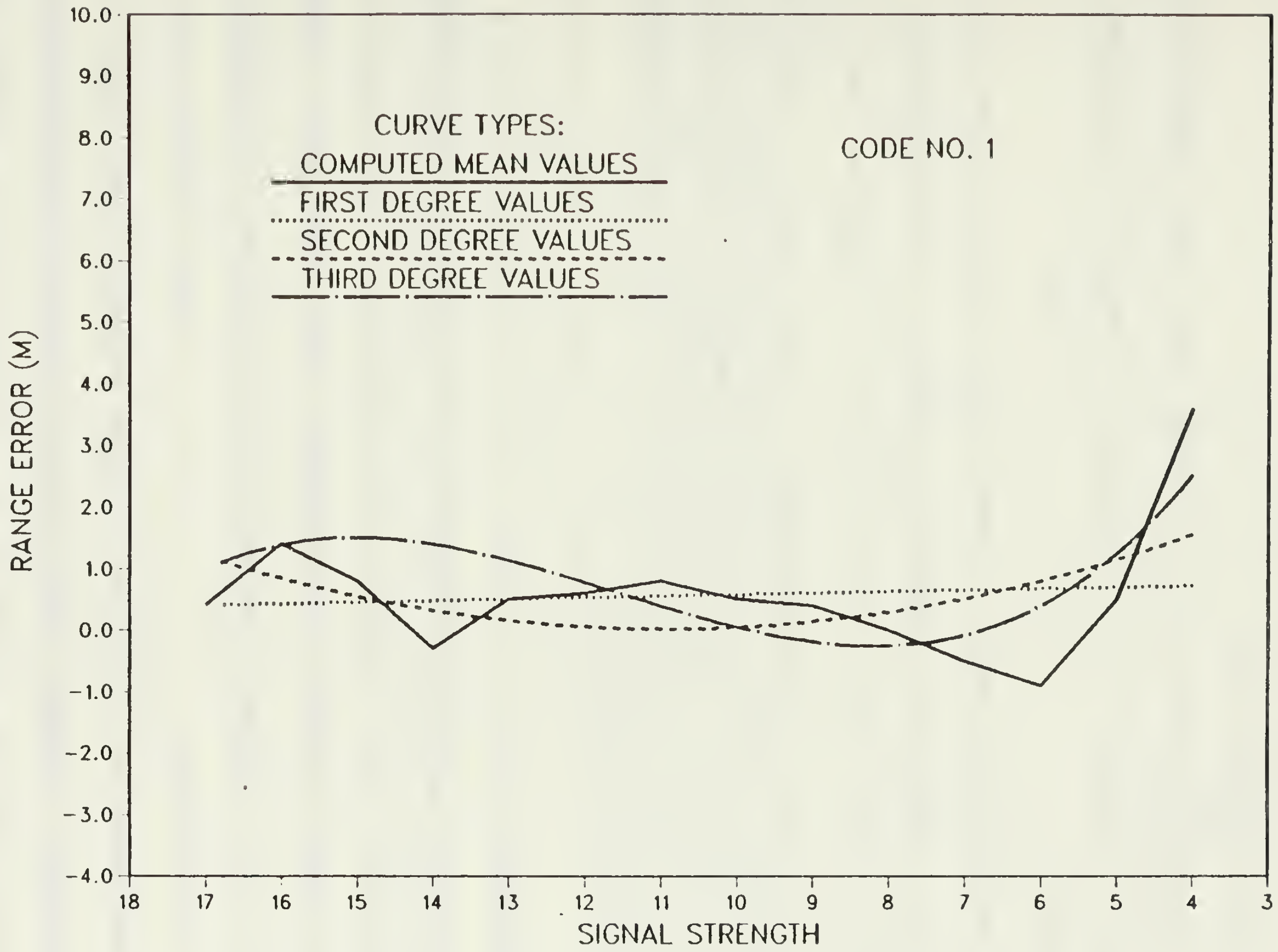



Figure 4.2 Regression Curves for Code 1

increases the degree of approximating polynomial so long as there is a decrease in the variance. Both codes had lowest variances for the third-degree curve. Knowing this, cubic regression coefficients were computed for each base line for the two codes (Table VII).

The coefficients for the base lines were computed using a Hewlett-Packard 41C calculator and regression program (SIGMAPOLYC).

The good agreement between cubic fits at base line B for each code and their respective overall curves suggests that a distance of about 2,500 meters is an optimum range over which to calibrate (using endpoints at sea level). The cubic regression curves for this distance adequately depict range error versus signal strength for all five base-line distances and three types of antennae.

## B. CONCLUSIONS

The optimum base-line length for obtaining a representative calibration with both calibration endpoints at sea level was closest to base line B (2,500 meters) for both codes 0 and 1. At present, NOS requires the base-line length to be between 700 and 3,000 meters.

The high-gain type antenna varied slightly more than the other two antenna types. High-gain calibration errors agreed to within 1 to 2 meters with the medium-gain and omnidirectional antenna results in all but 6 of the 90 calibration sets.

TABLE VII

COMPUTED VARIANCES FOR HIGHER DEGREE CURVES

| Polynomial Degree | Variance |
|---|---|
| Code 0: | |
| 1 | 1.78 |
| 2 | 1.03 |
| 3 | 0.43 |
| 4 | 0.43 |
| Code 1: | |
| 1 | 1.10 |
| 2 | 0.87 |
| 3 | 0.54 |
| 4 | 0.54 |

The fitted polynomials (Figs. 4.1 and 4.2) had maximum discrepancies in range error of 1.5 and 2.0 meters for codes 0 and 1, respectively. To improve the quality of fit, one could increase the number of data points.

Another possibility is to resolve a calibration curve into exponential and linear components and fitting each component separately. The expanded scale of the Falcon 484 offers a greater range of signal strengths over which to calibrate. The improved mean values would improve the fit of the function to the observed data.

It may be prudent to set operational distance limits for the medium-gain and omnidirectional antennae. Both antennae were lacking in data points at the higher signal strengths for calibrations at distances greater than base line B (2,500 meters). Likewise, a minimum distance may be needed for

high-gain antennae as shown by the code 0, base line A range-error plots (Appendix B). The anomalies suggest that calibrating with a high-gain antenna at too close a distance (perhaps less than 1,000 meters) may result in erroneous correctors.

## C. RECOMMENDATIONS

Study the concept of rejecting data below MASS and fitting the remaining data to a linear curve.

Investigate spline curve fitting or the resolving of a calibration curve into linear and exponential components before deciding upon future calibration procedures.

Give consideration to mathematically determining the MASS of a curve prior to fitting. Further statistical tests could then be applied to data below the MASS to determine whether it should be rejected.

Plot mean range error versus signal strength for each base line and for the cumulative mean range errors for each of the two codes, thus showing which base line's data influences the overall mean curve the most. A comparison should be made using a single, mean corrector MRS III code, as is presently done, with the predictive results obtained from curve fitting. The comparison should consider the allowable positioning errors for different survey scales.

Review present base-line calibration procedures with respect to the findings of this thesis. Specifically, evaluate the optimum distance of 2,500 meters with a range average setting of 75 and a high-gain antenna.

## APPENDIX A

## MINI-RANGER III SYSTEM SPECIFICATIONS

### Overall System Power Requirements

| | |
|---|---|
| **Range Console** | |
| Input Voltage | 105 to 125 volts AC |
| | 12 to 32 volts DC |
| Power Consumption | 60 watts AC |
| | 40 watts DC |
| **RT Unit** | |
| Input voltage | 22 to 32 volts DC |
| Power Consumption (at 27 VDC) | |
| No interrogation (standby) | 9 watts |
| Normal interrogation | 16 watts |
| **Transponder** | |
| | 22 to 32 volts DC |
| Power Consumption (at 27 VDC) | |
| No Interrogation (standby) | 8 watts |
| Normal Interrogation | 15 watts |

## Transmission Frequencies

<u>RT Unit</u>

| | |
|---|---|
| Transmit | 5570 MHz |
| Receive | 5480 MHz |

<u>Shore Transponder</u>

| | |
|---|---|
| Transmit | 5480 MHz |
| Receive | 5570 MHz |

## Number of Users

With range averaging and multi-user options installed, Motorola recommends no more than five range consoles operate in a project area. Although the consoles may have different codes, they will still lock each other out when transmitting to a shore station.

## Accuracy of the System

The following figures are based on one-sigma standard deviation. This means that 68.23 percent of all readings will fall within the quoted accuracy.

| Range Average Setting | Accuracy (in meters) |
|---|---|
| 1 | 3.00 |
| 5 | 2.12 |
| 20 | 1.15 |
| 40 | 1.06 |
| 75 | 0.78 |

## Antennae and Beam Characteristics

<u>Receiver-Transmitter</u> (<u>RT</u> <u>unit</u>)

| | |
|---|---|
| Gain | 6 db |
| Horizontal | 360 degrees (omnidirectional) |
| Vertical | 25 degrees |

<u>Shore</u> <u>Transponder</u>

Medium-Gain Antenna

| | |
|---|---|
| Gain | 13 db |
| Horizontal | 80 degrees |
| Vertical | 15 degrees |

High-Gain Antenna

| | |
|---|---|
| Gain | 19 db |
| Horizontal | 80 degrees |
| Vertical | 5 degrees |

Omnidirectional Antenna

Same characteristics as the RT unit antenna.

## Range of System Operation

The system is line-of-sight. Though Motorola's operation manual claims a maximum range of 37,000 meters, this distance is undoubtedly achieved by increasing the elevation of either or both the RT unit and shore transponder antennae.

| Antenna Type | Maximum Range (in meters) |
|---|---|
| Medium-Gain | 32,180 |
| High-Gain | 64,360 |
| Omnidirectional | unknown but less than Medium-Gain. |

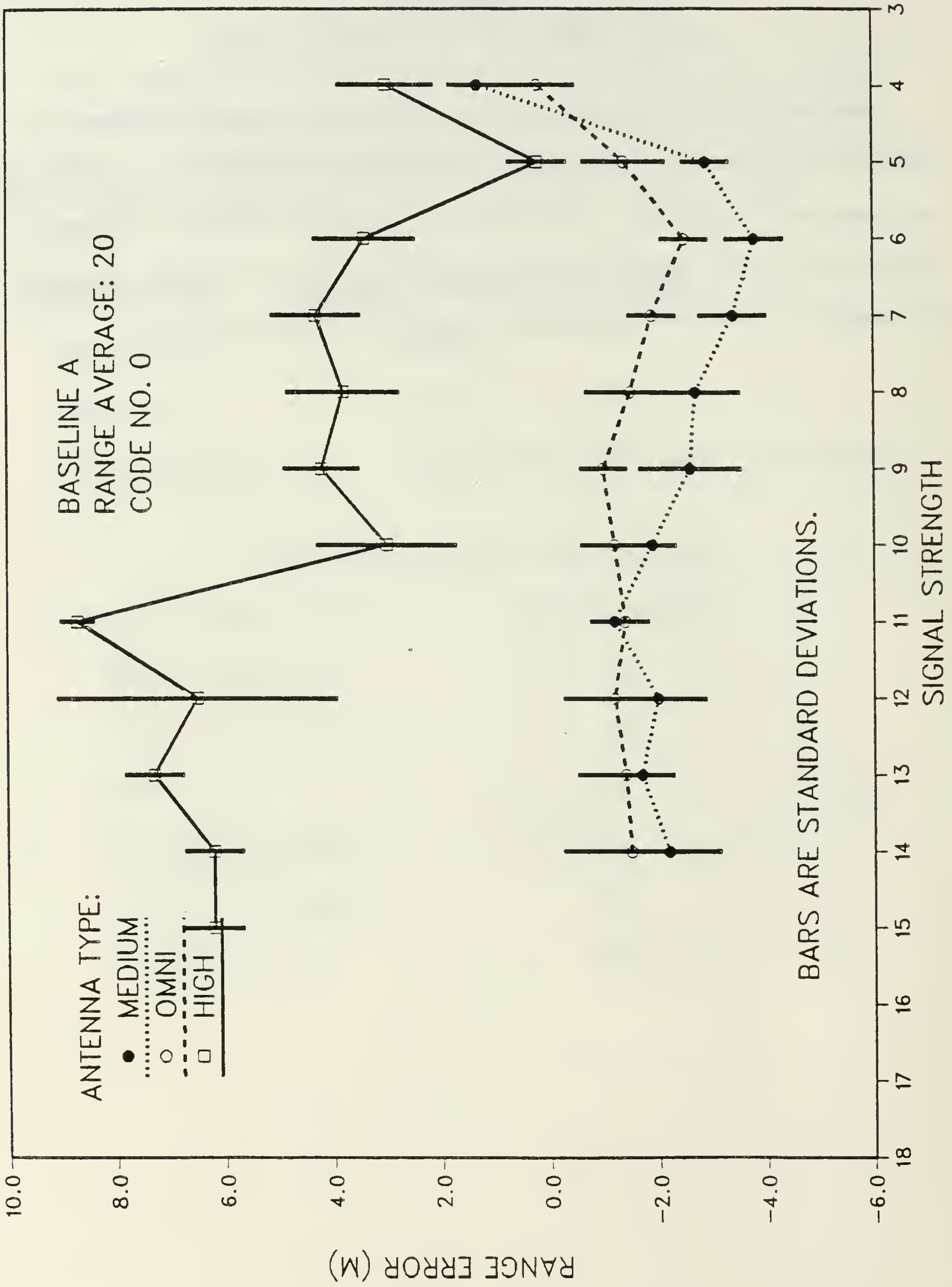
## Motorola Options used by NOS

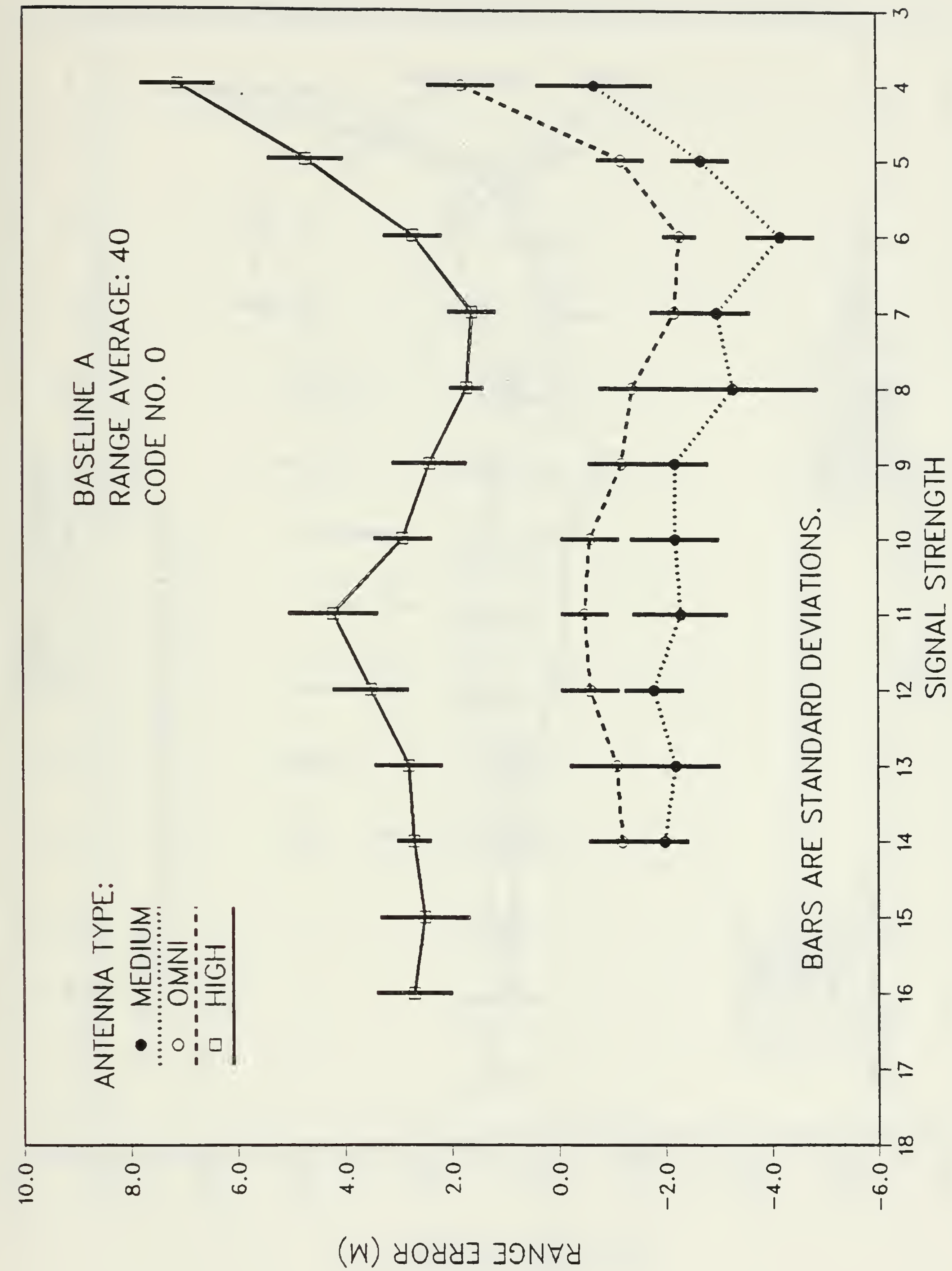
| Option Description | Option Number |
|---|---|
| Signal Strength | 2 |
| Range Averaging | 4 |
| Multiuser | 5 |
| Byte Test Module | 11 |
| 30-Minute Standby | 15 |
| 16-Code Option | 46, 47 |

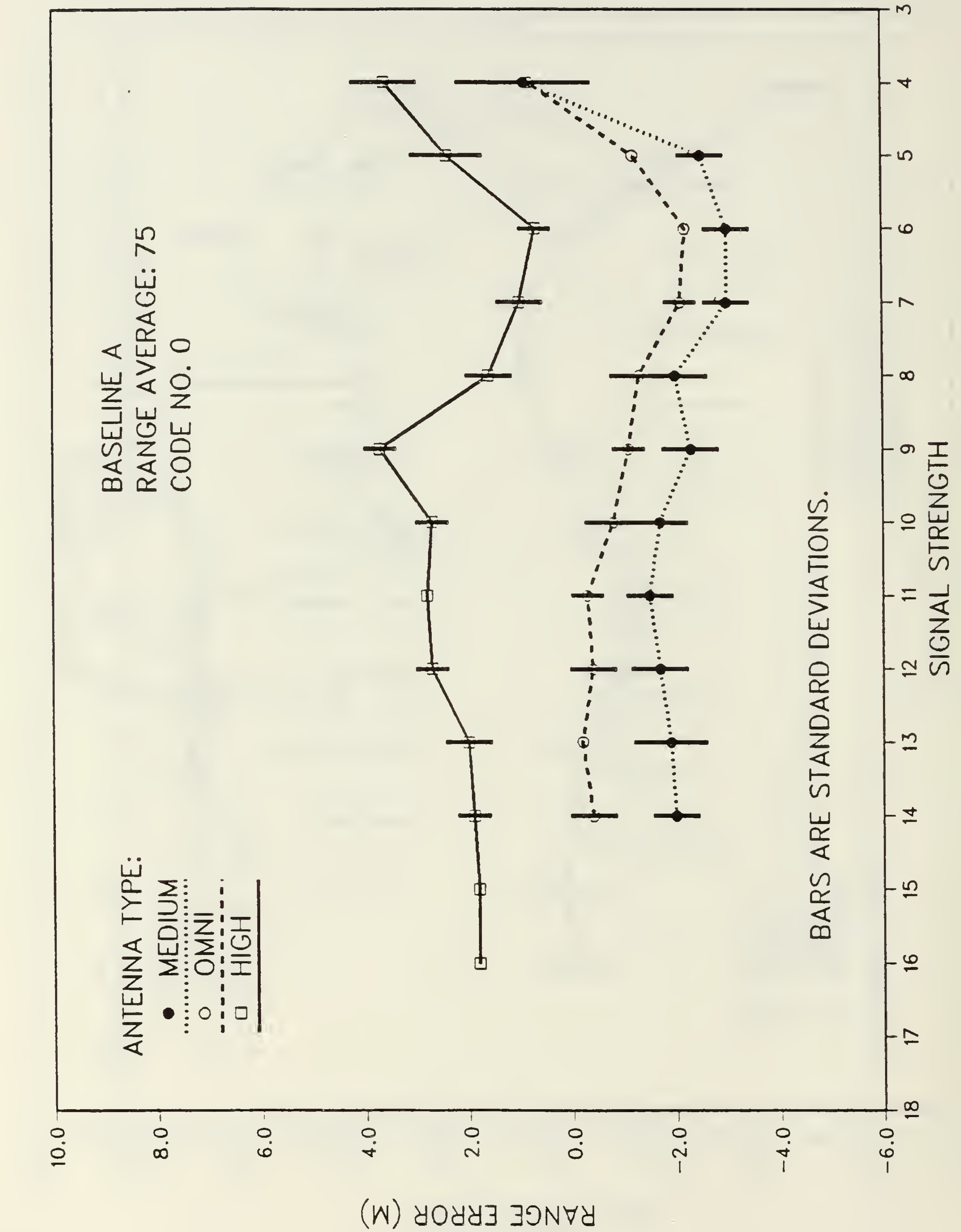
# APPENDIX B

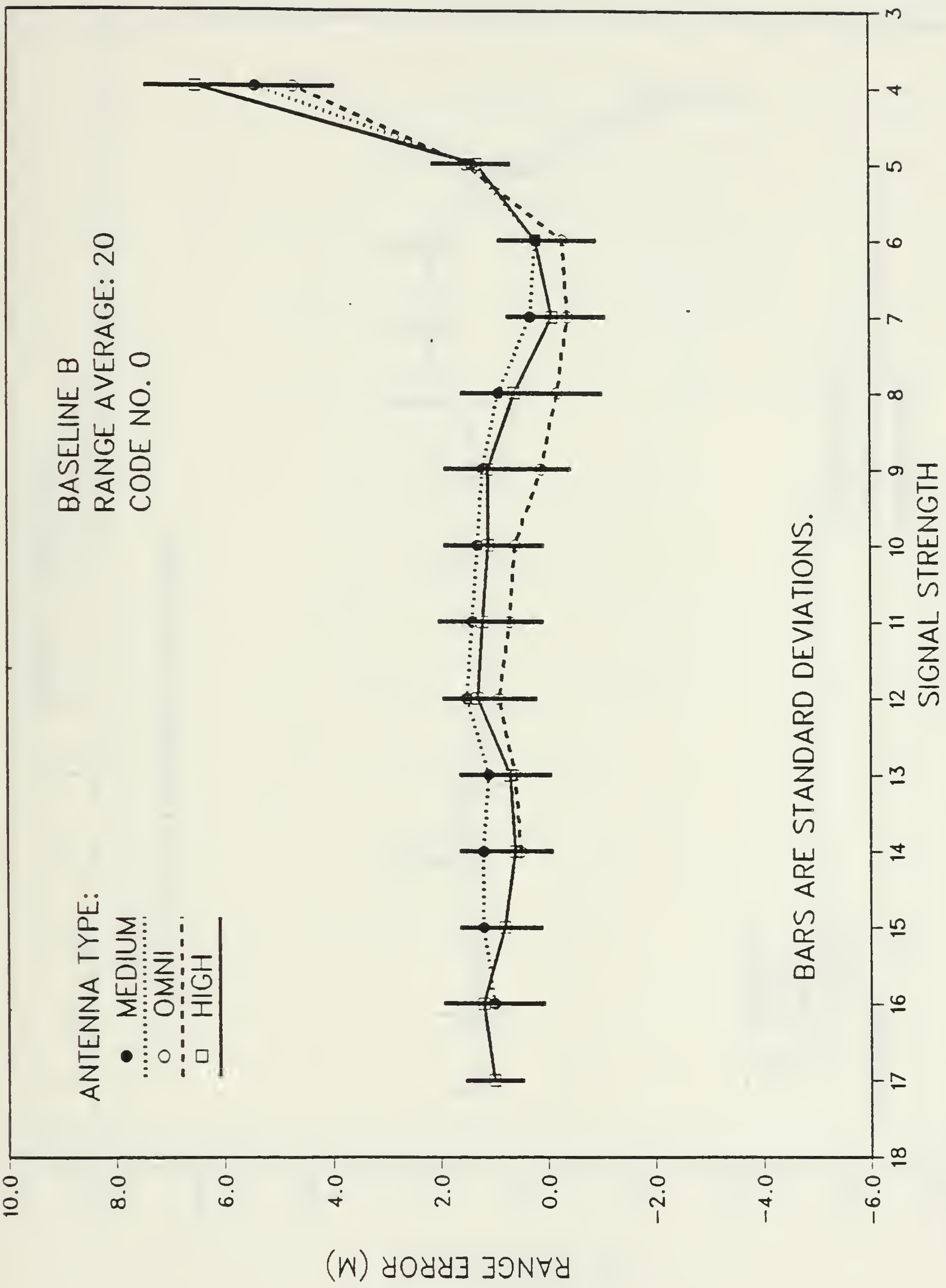
## RANGE ERROR AND STATISTICAL PLOTS

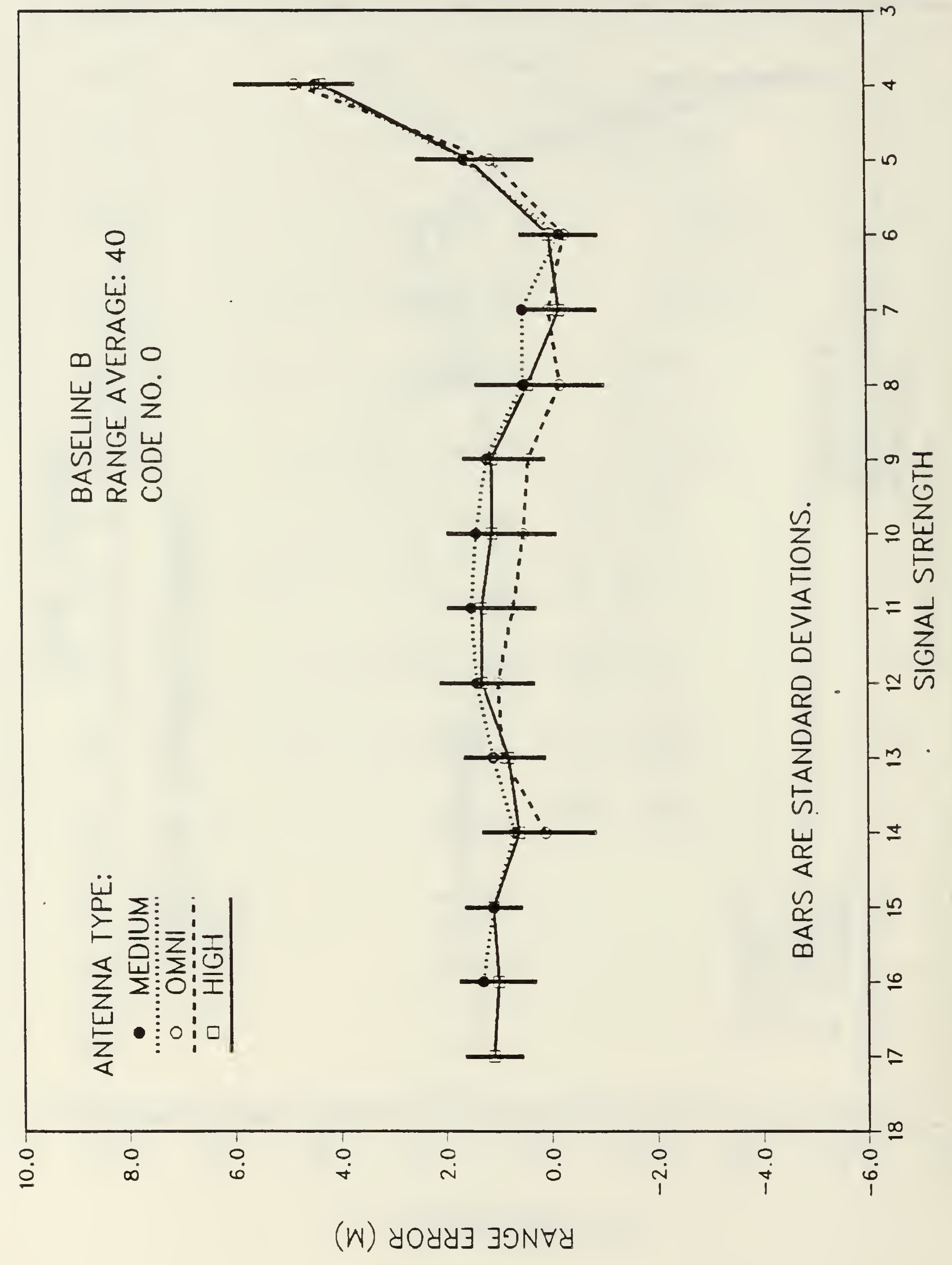
The following graphs are (1) range error versus signal strength (including standard deviations) for each calibration set (pages 72 through 101) and (2) scatter diagrams of mean range error (for each signal strength) versus signal strength for each of two MRS III codes (pages 102 through 113).

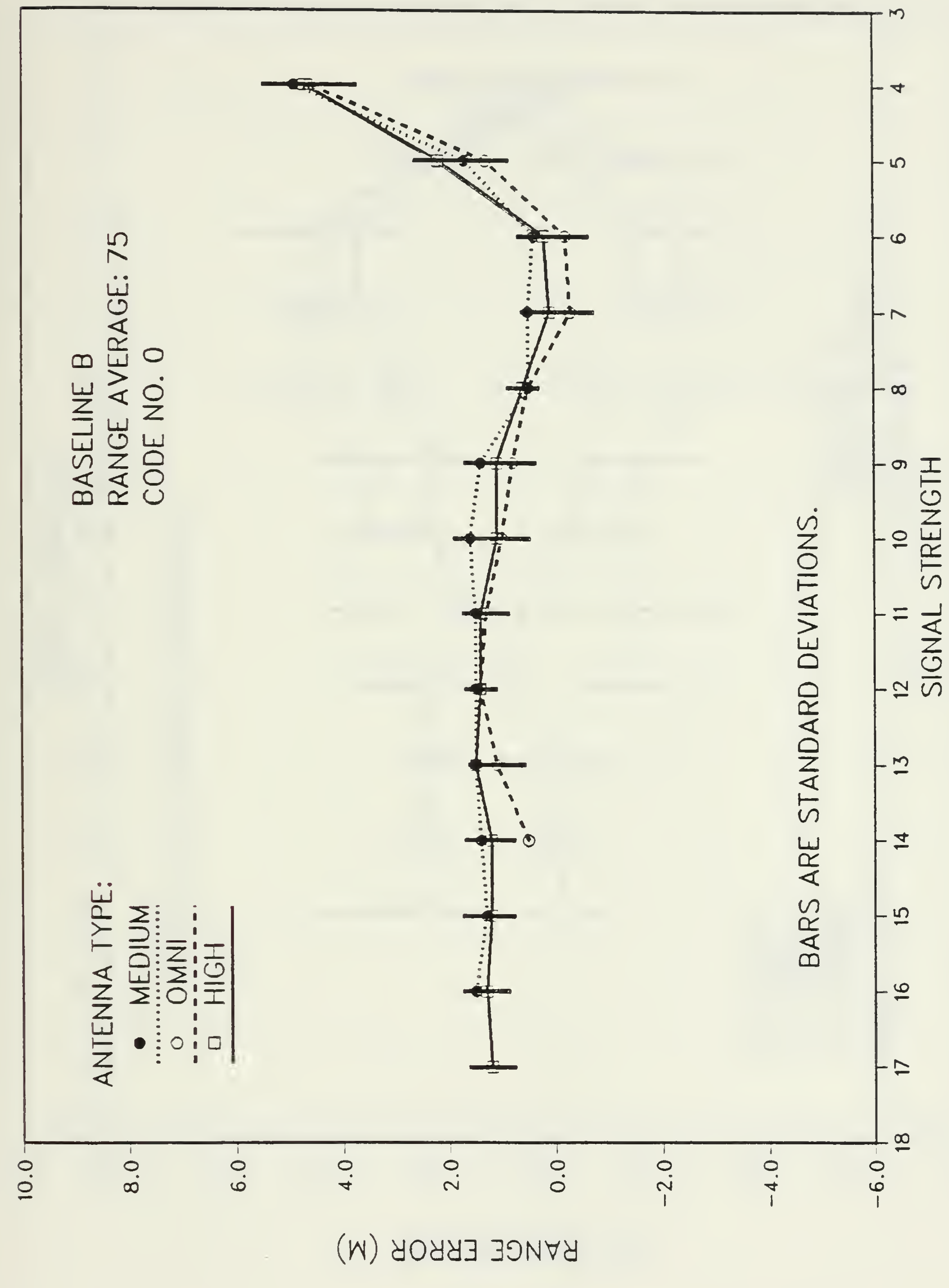

BASELINE A
RANGE AVERAGE: 20
CODE NO. 0
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

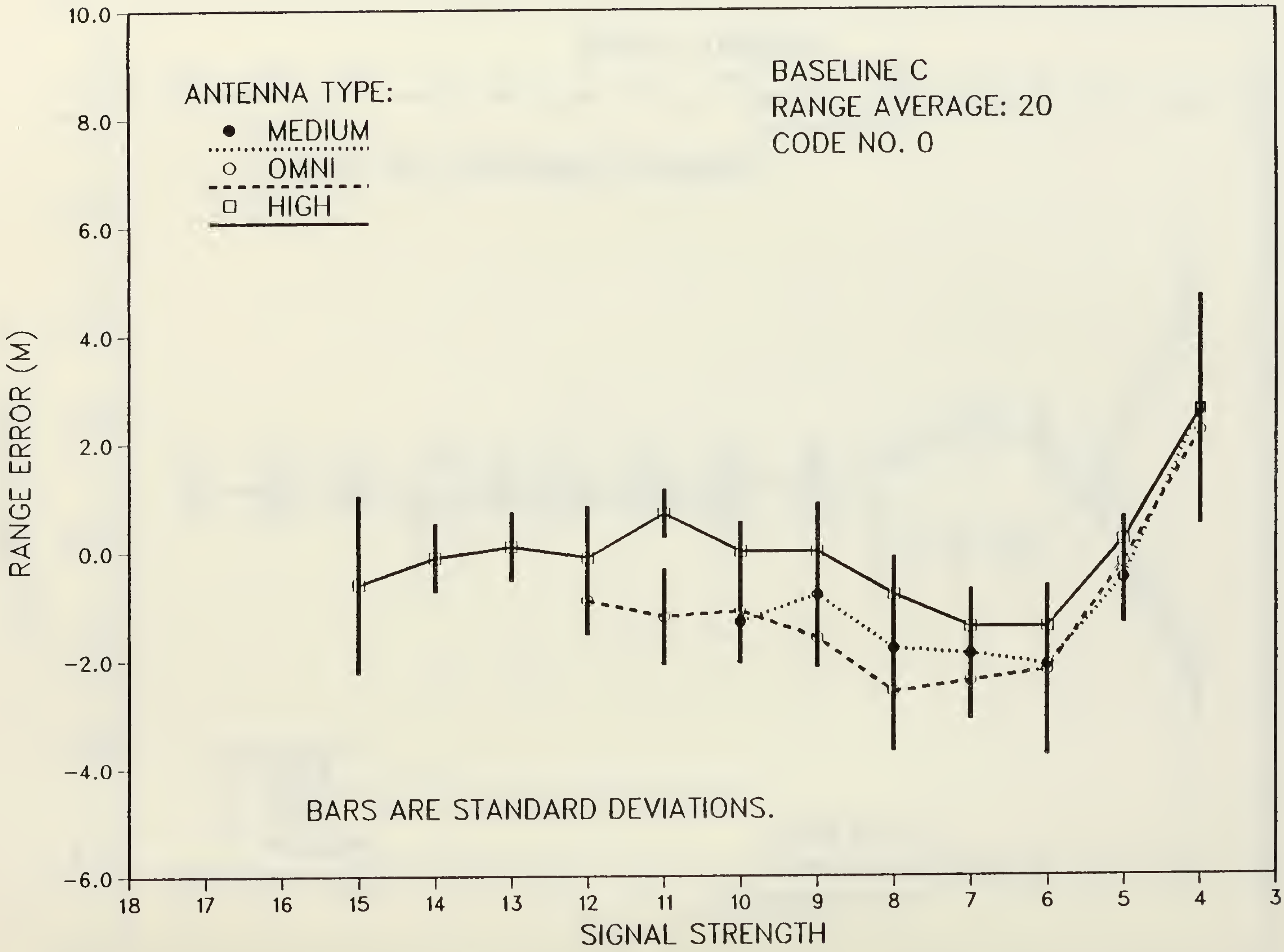

BASELINE A
RANGE AVERAGE: 40
CODE NO. 0
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
SIGNAL STRENGTH
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18


BASELINE A
RANGE AVERAGE: 75
CODE NO. 0
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

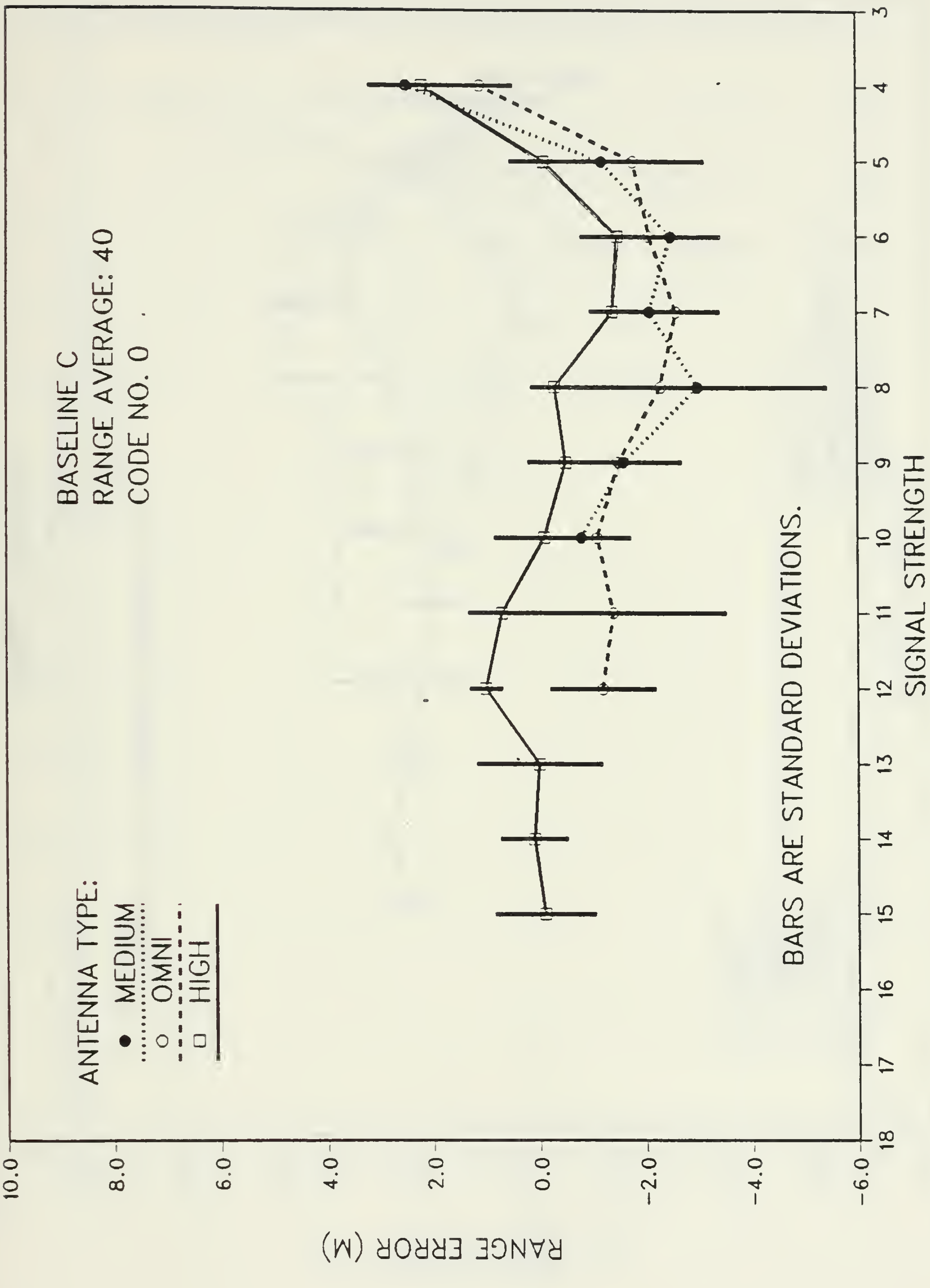

BASELINE B
RANGE AVERAGE: 20
CODE NO. 0
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
SIGNAL STRENGTH
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

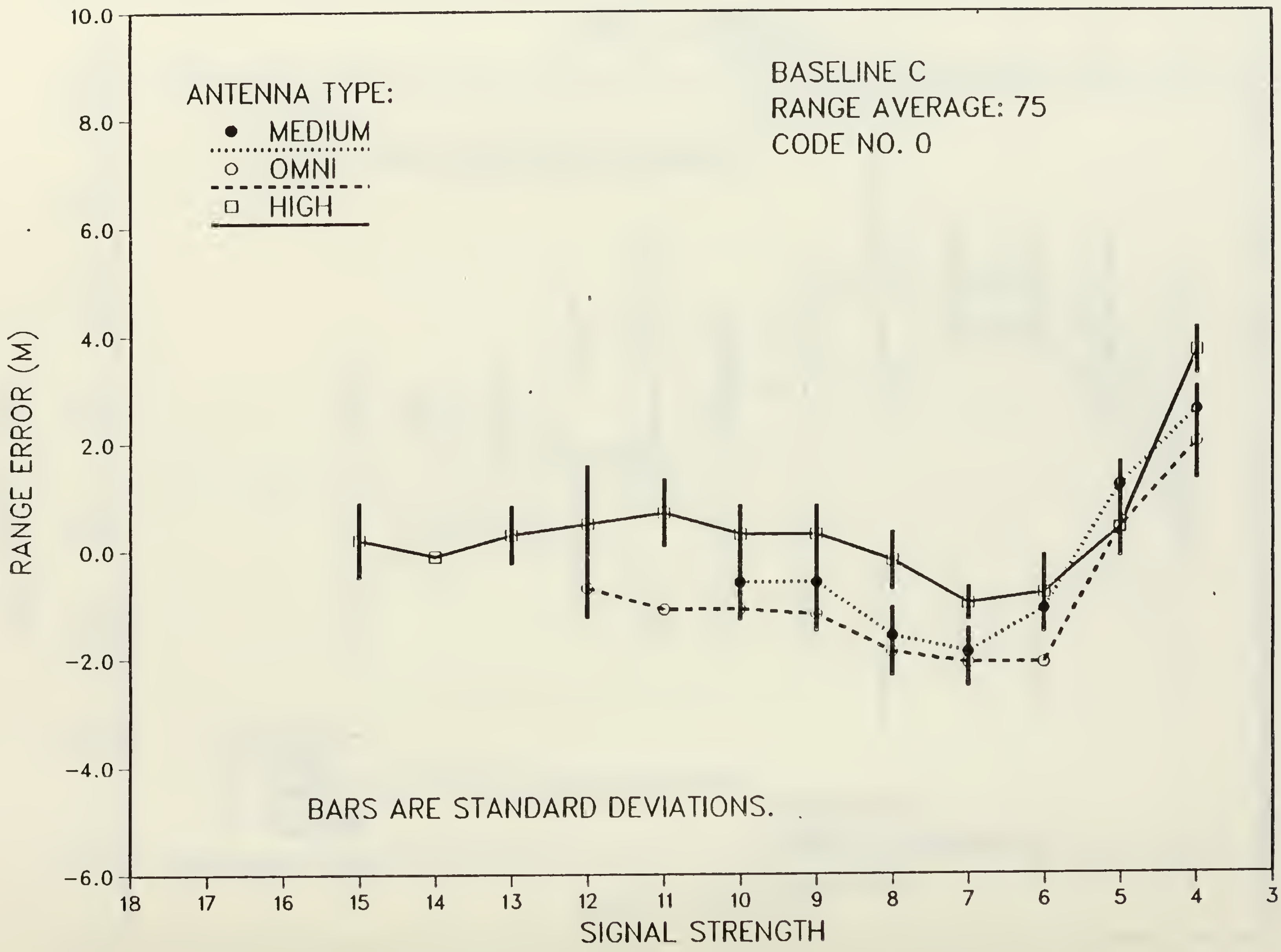

BASELINE B
RANGE AVERAGE: 40
CODE NO. 0
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
SIGNAL STRENGTH
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18


BASELINE B
RANGE AVERAGE: 75
CODE NO. 0
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
SIGNAL STRENGTH
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

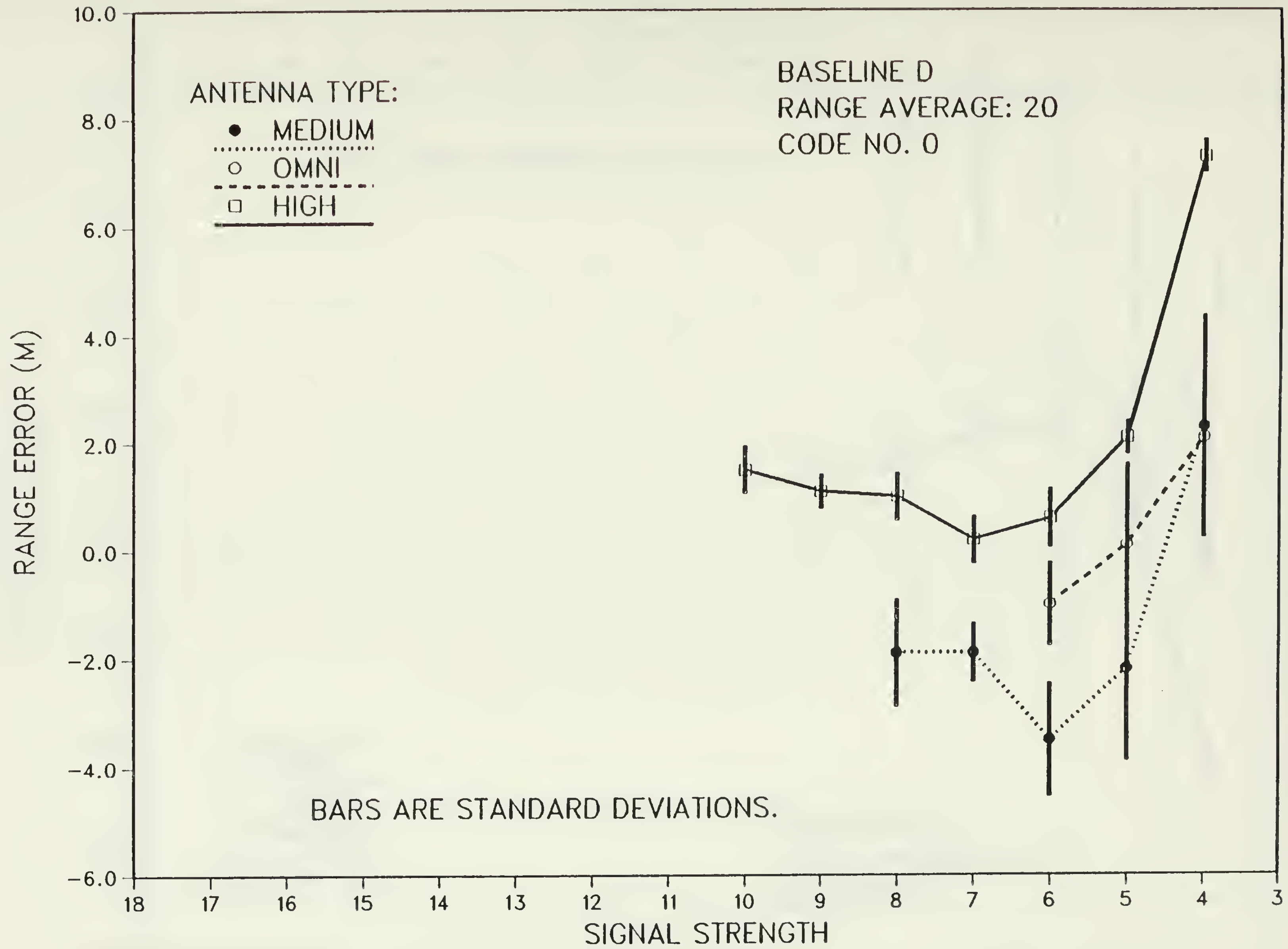


ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BASELINE C
RANGE AVERAGE: 20
CODE NO. 0
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3

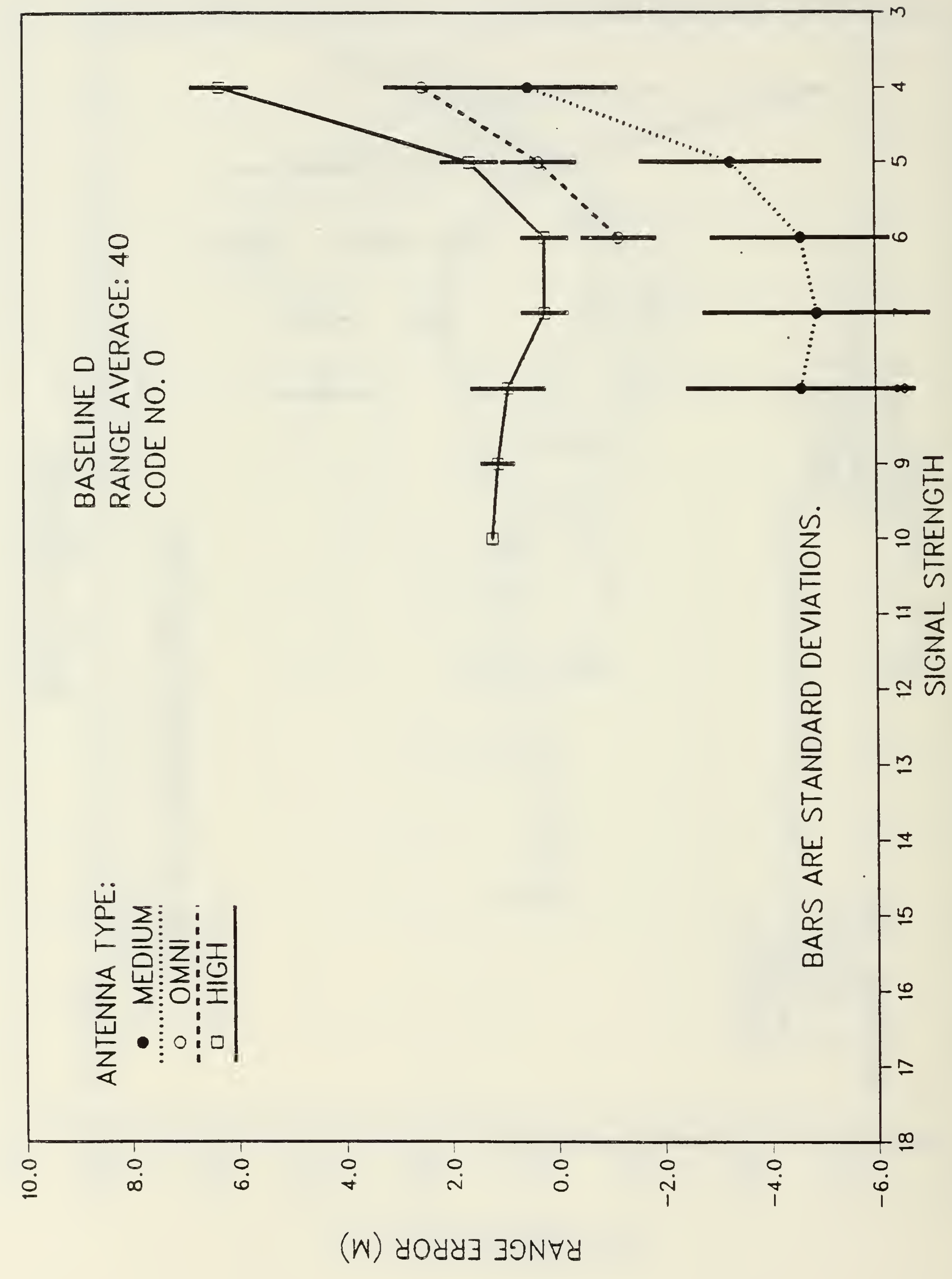

BASELINE C
RANGE AVERAGE: 40
CODE NO. 0
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

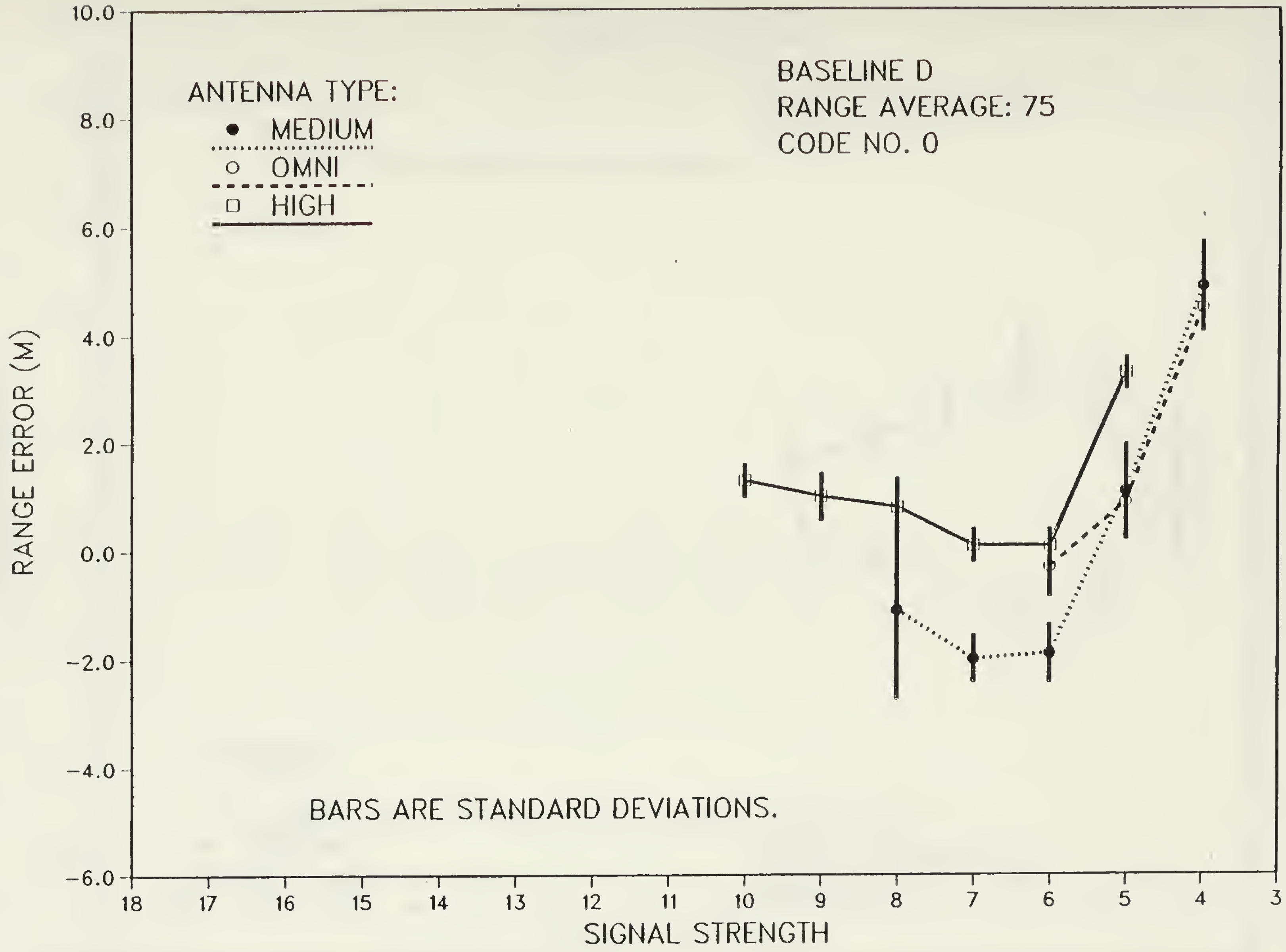


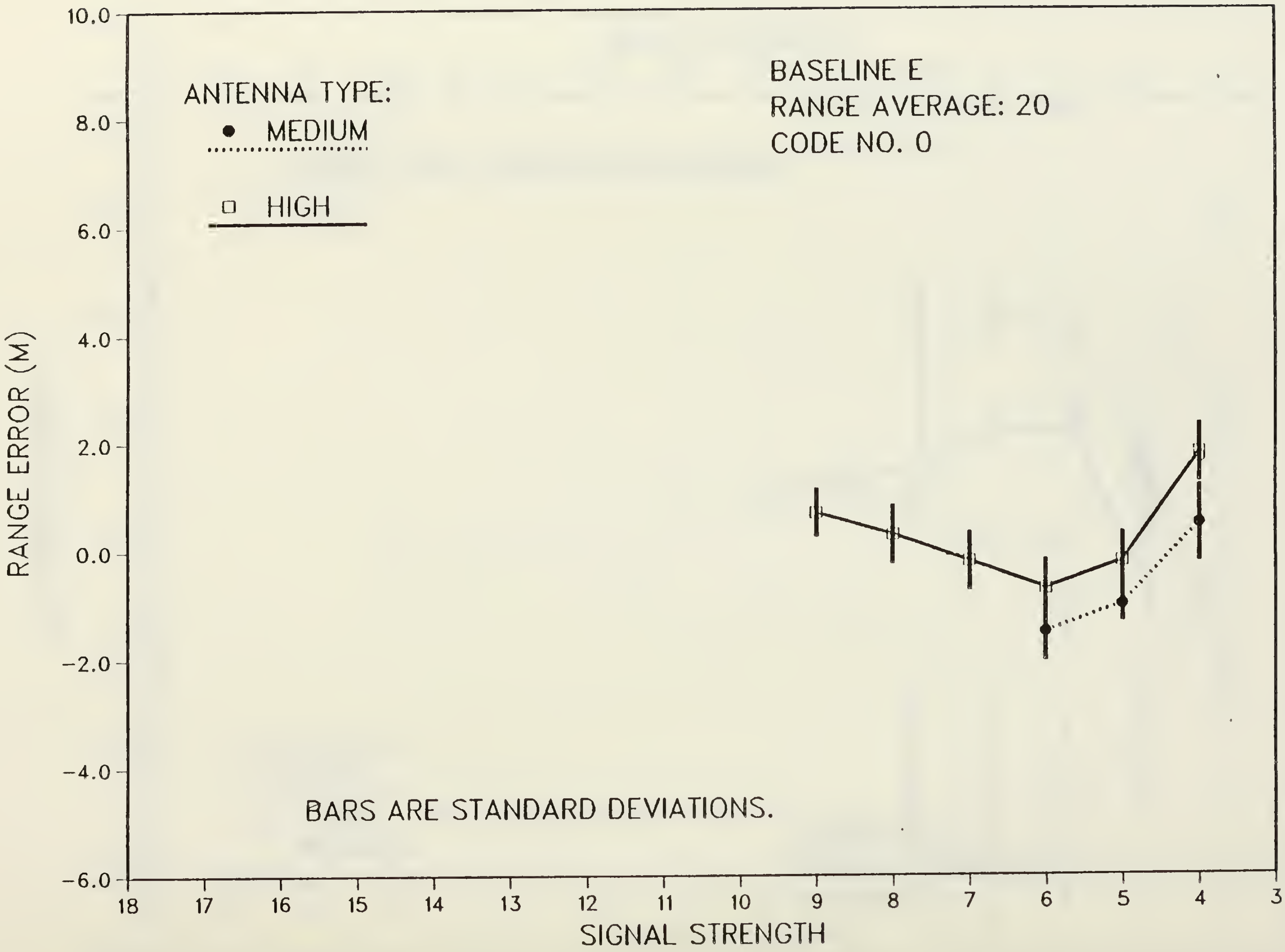
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BASELINE C
RANGE AVERAGE: 75
CODE NO. 0
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
SIGNAL STRENGTH
BARS ARE STANDARD DEVIATIONS.

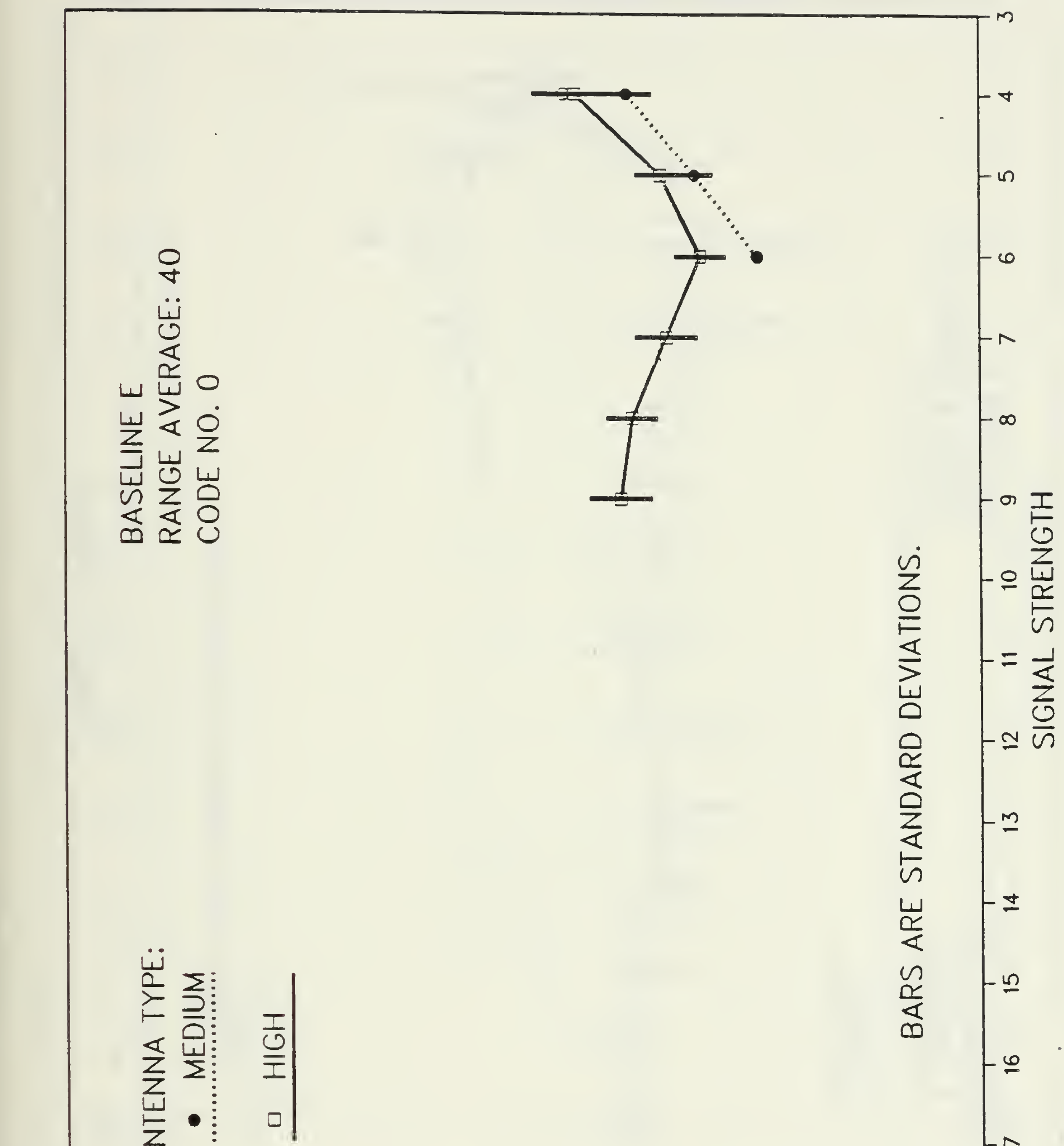


ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BASELINE D
RANGE AVERAGE: 20
CODE NO. 0
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
SIGNAL STRENGTH
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3

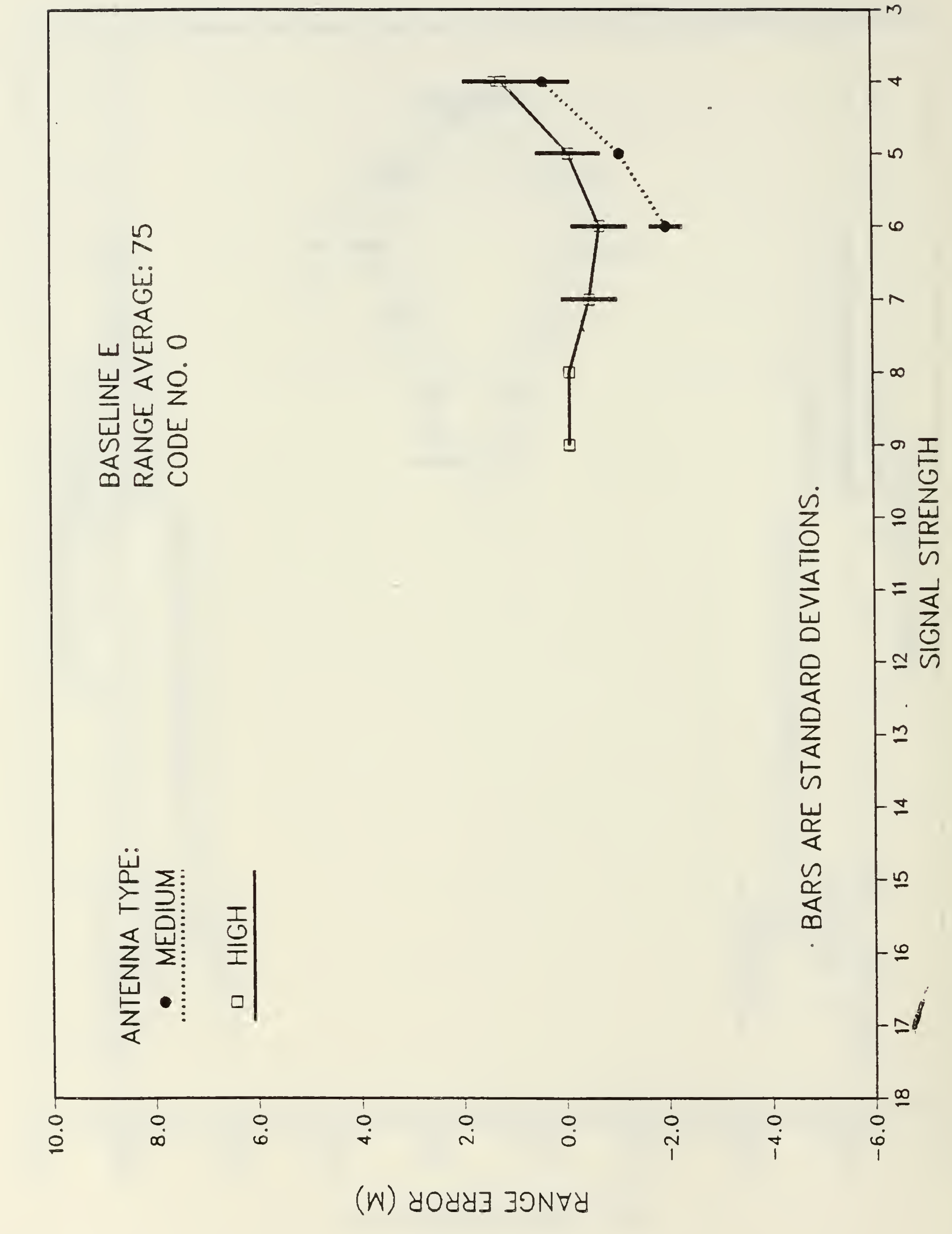

BASELINE D
RANGE AVERAGE: 40
CODE NO. 0
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
SIGNAL STRENGTH
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
9
10
11
12
13
14
15
16
17
18

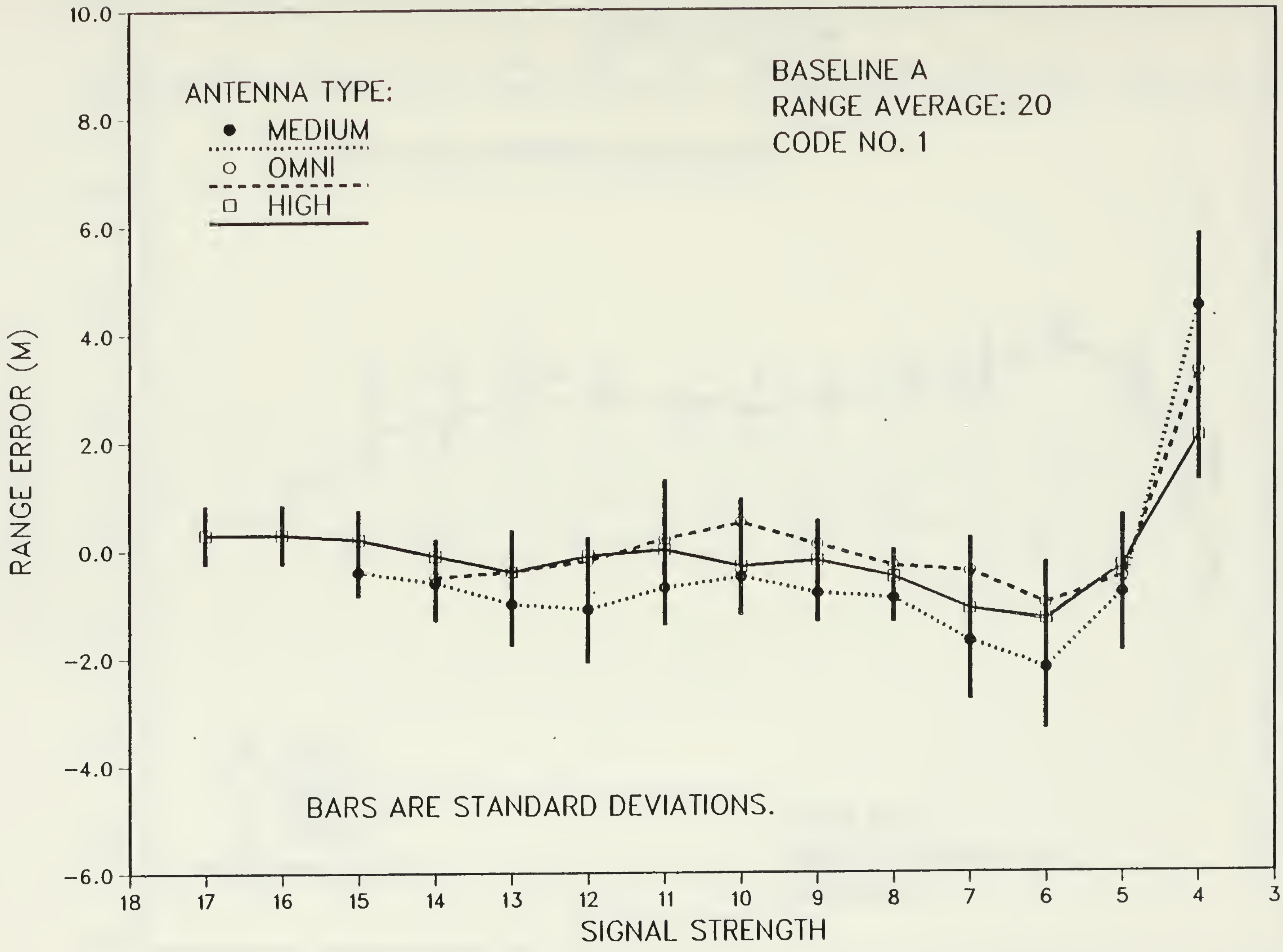

BASELINE D
RANGE AVERAGE: 75
CODE NO. 0
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3


ANTENNA TYPE:
MEDIUM
HIGH
BASELINE E
RANGE AVERAGE: 20
CODE NO. 0
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3

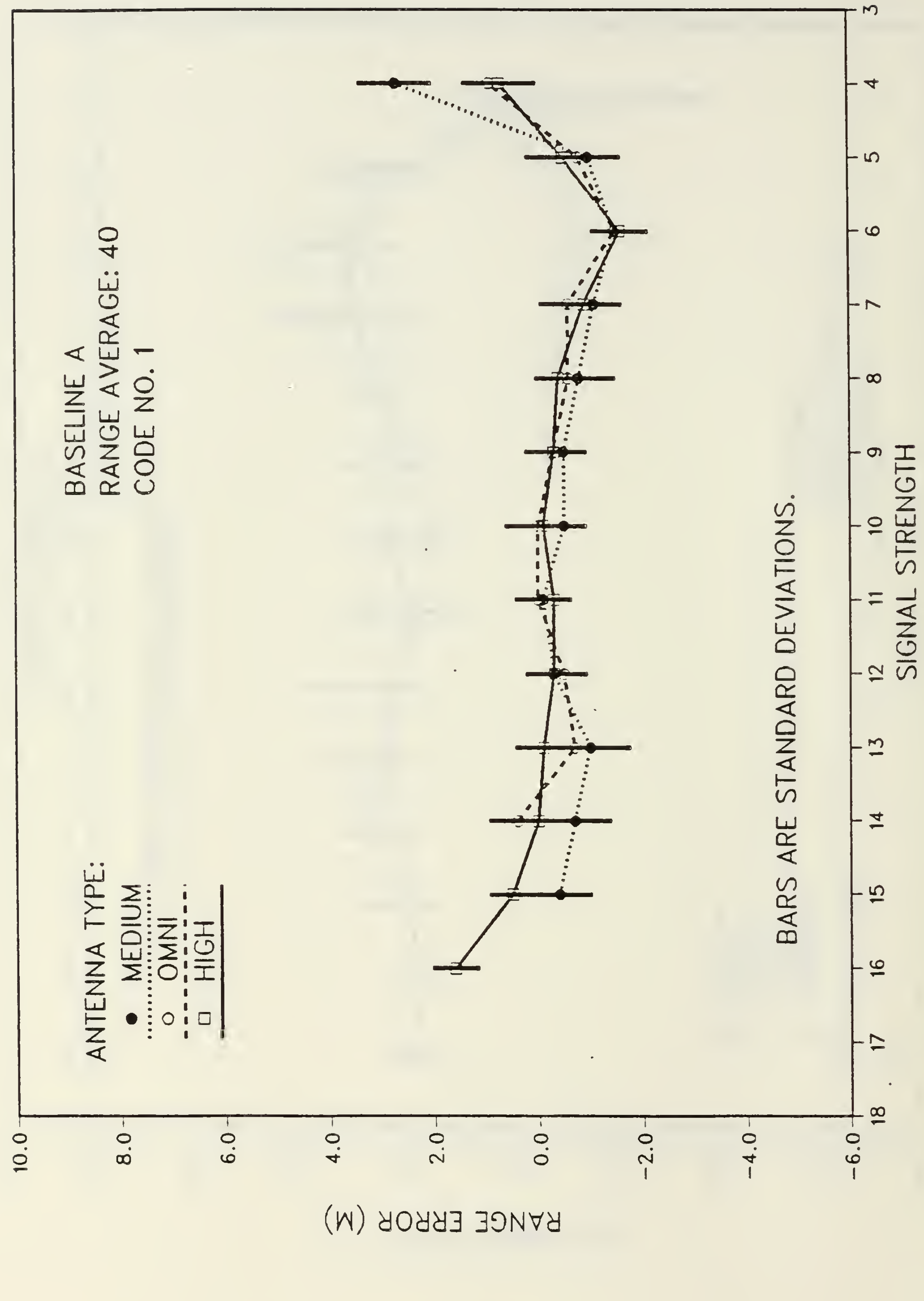


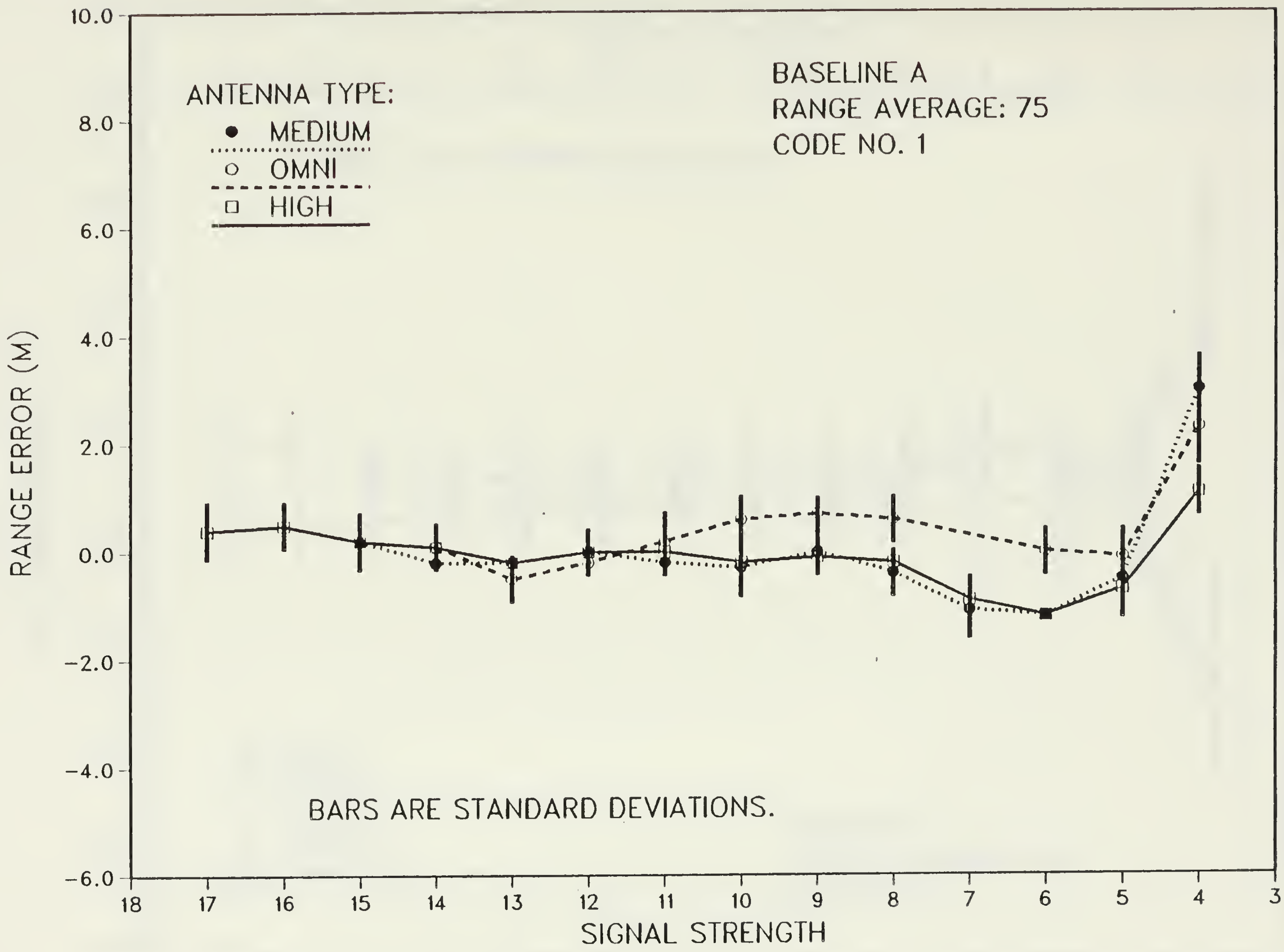
BASELINE E
RANGE AVERAGE: 40
CODE NO. 0
ANTENNA TYPE:
MEDIUM
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18


BASELINE E
RANGE AVERAGE: 75
CODE NO. 0
ANTENNA TYPE:
MEDIUM
HIGH
BARS ARE STANDARD DEVIATIONS.
SIGNAL STRENGTH
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

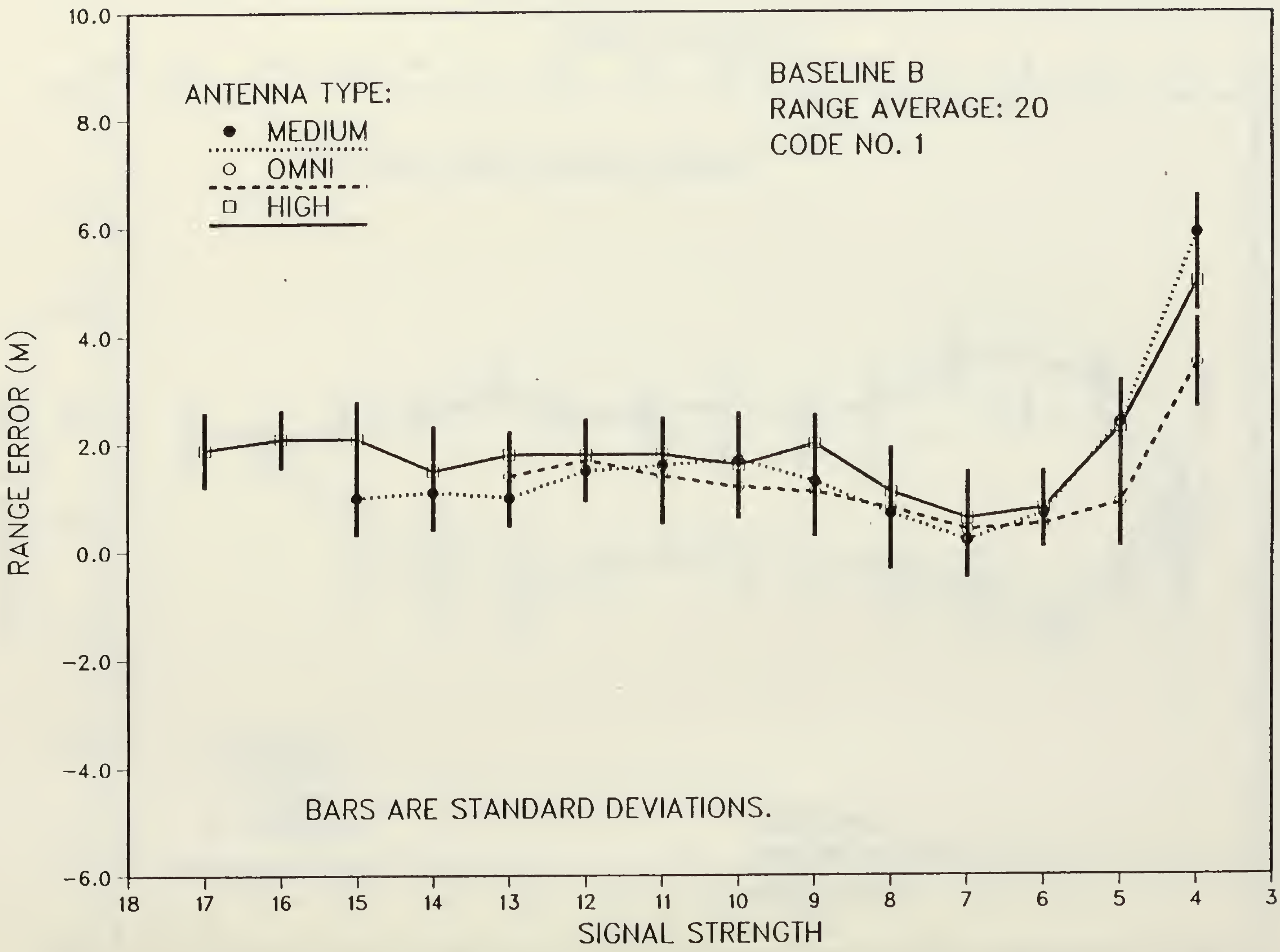


ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BASELINE A
RANGE AVERAGE: 20
CODE NO. 1
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3

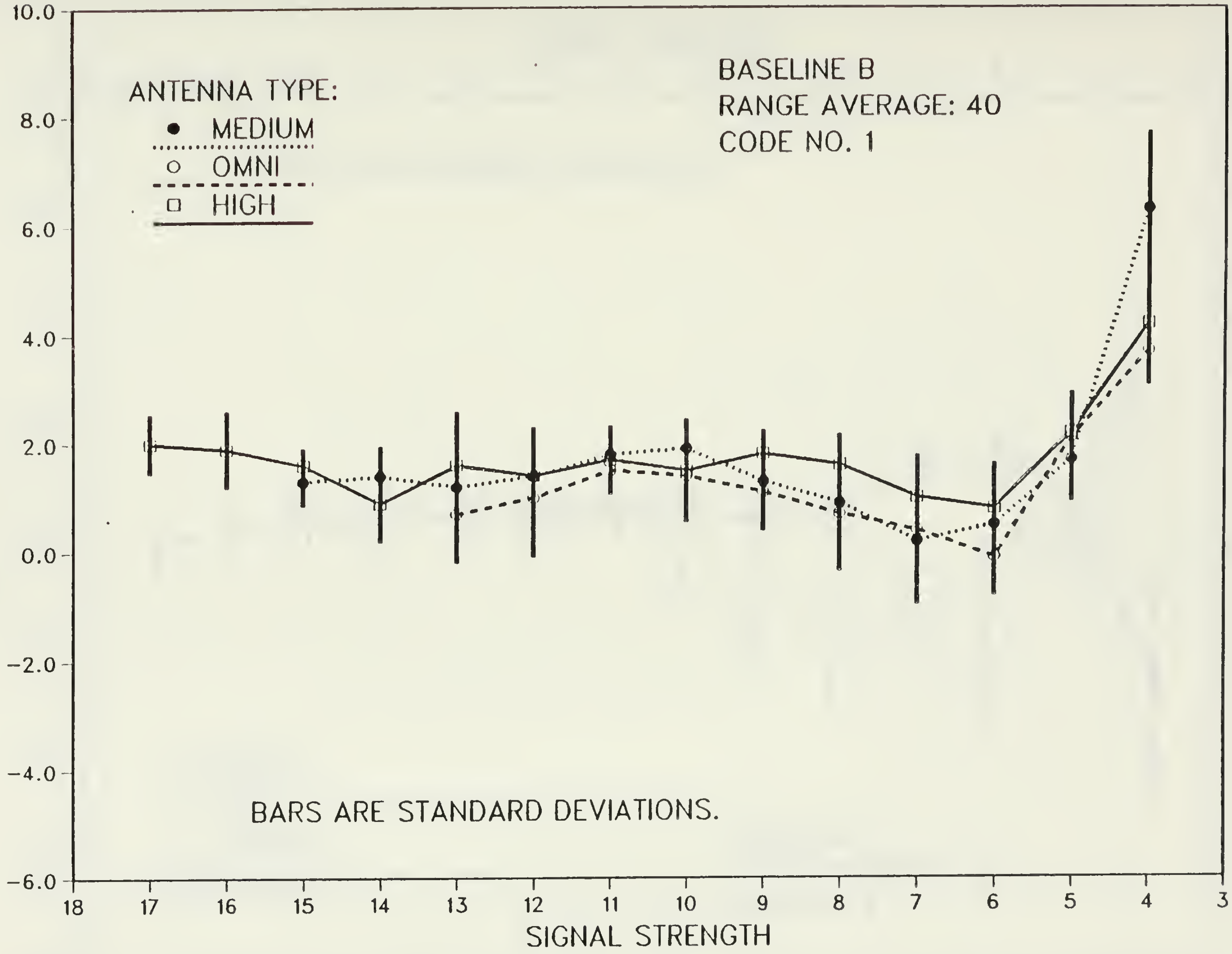

BASELINE A
RANGE AVERAGE: 40
CODE NO. 1
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18



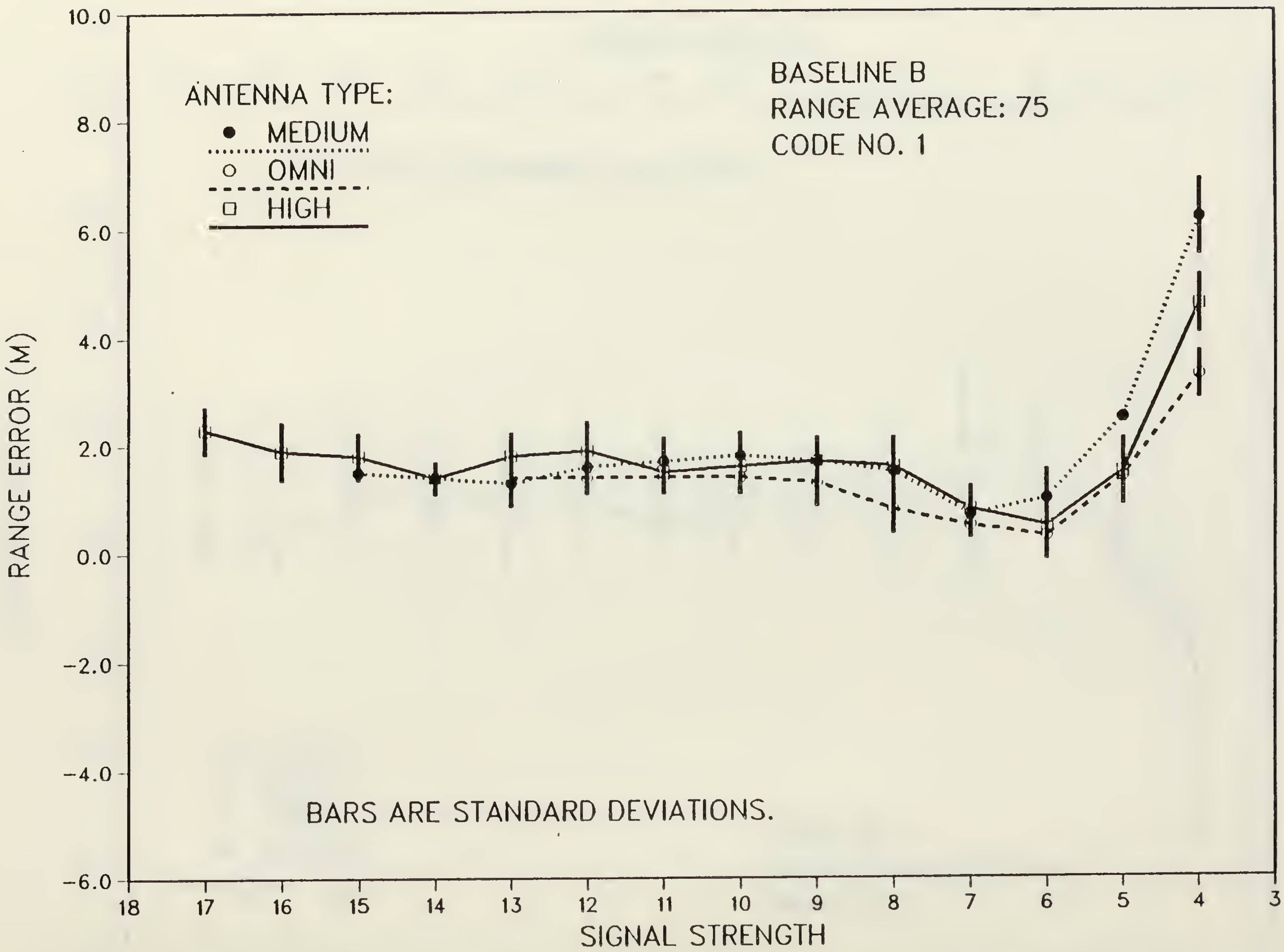
BASELINE A
RANGE AVERAGE: 75
CODE NO. 1
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3

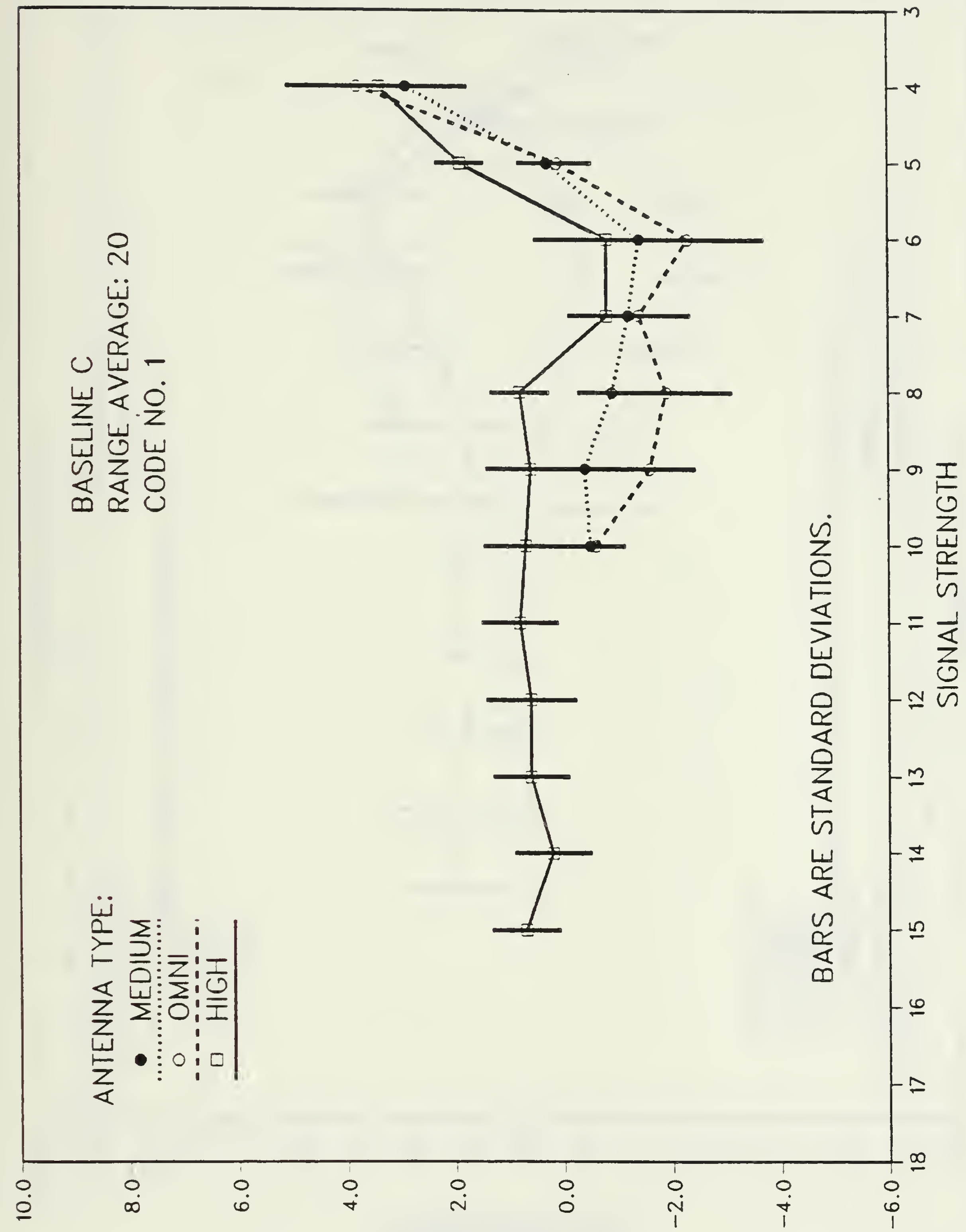


BASELINE B
RANGE AVERAGE: 20
CODE NO. 1
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
SIGNAL STRENGTH
BARS ARE STANDARD DEVIATIONS.

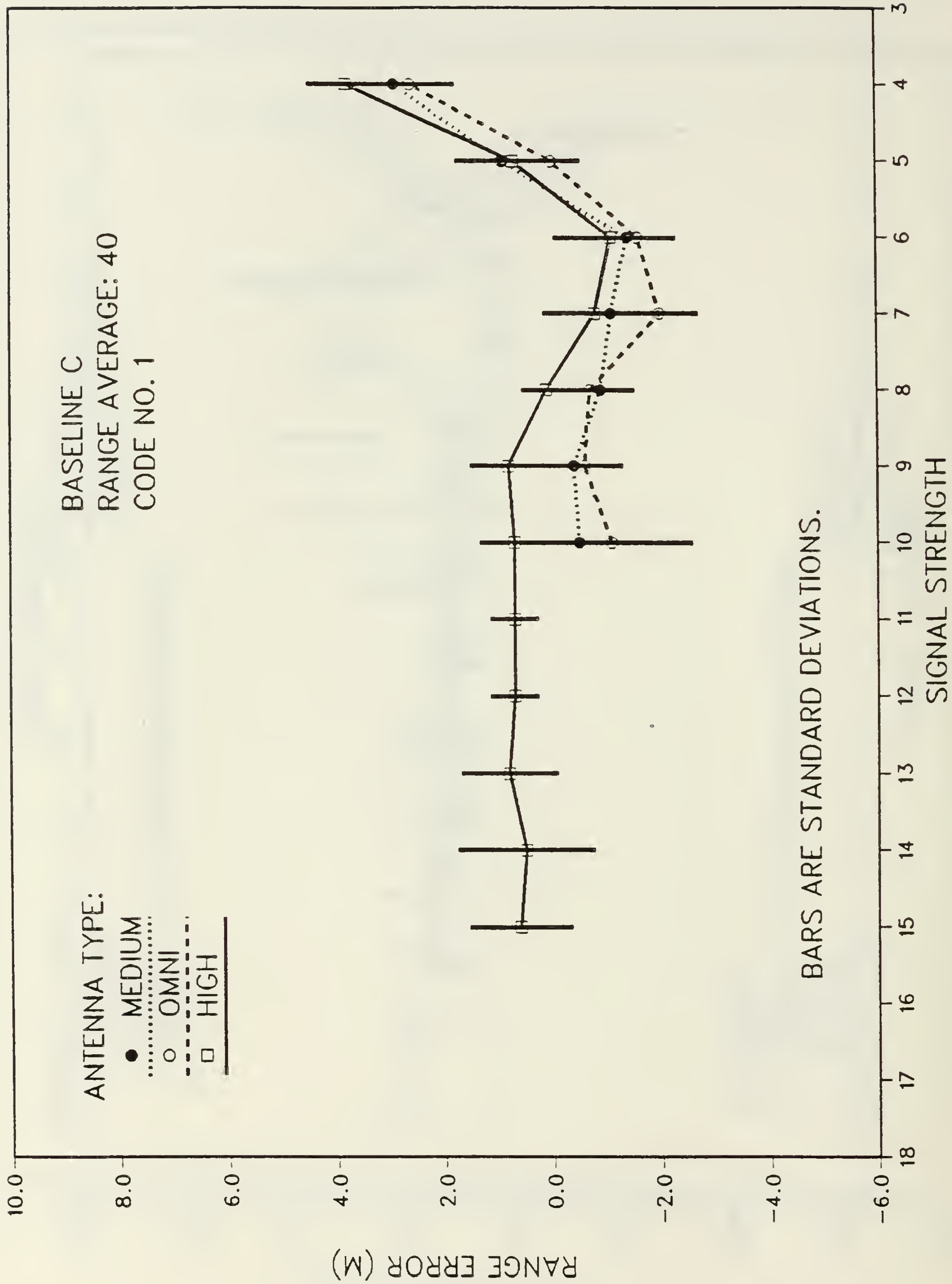


BASELINE B
RANGE AVERAGE: 40
CODE NO. 1
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3

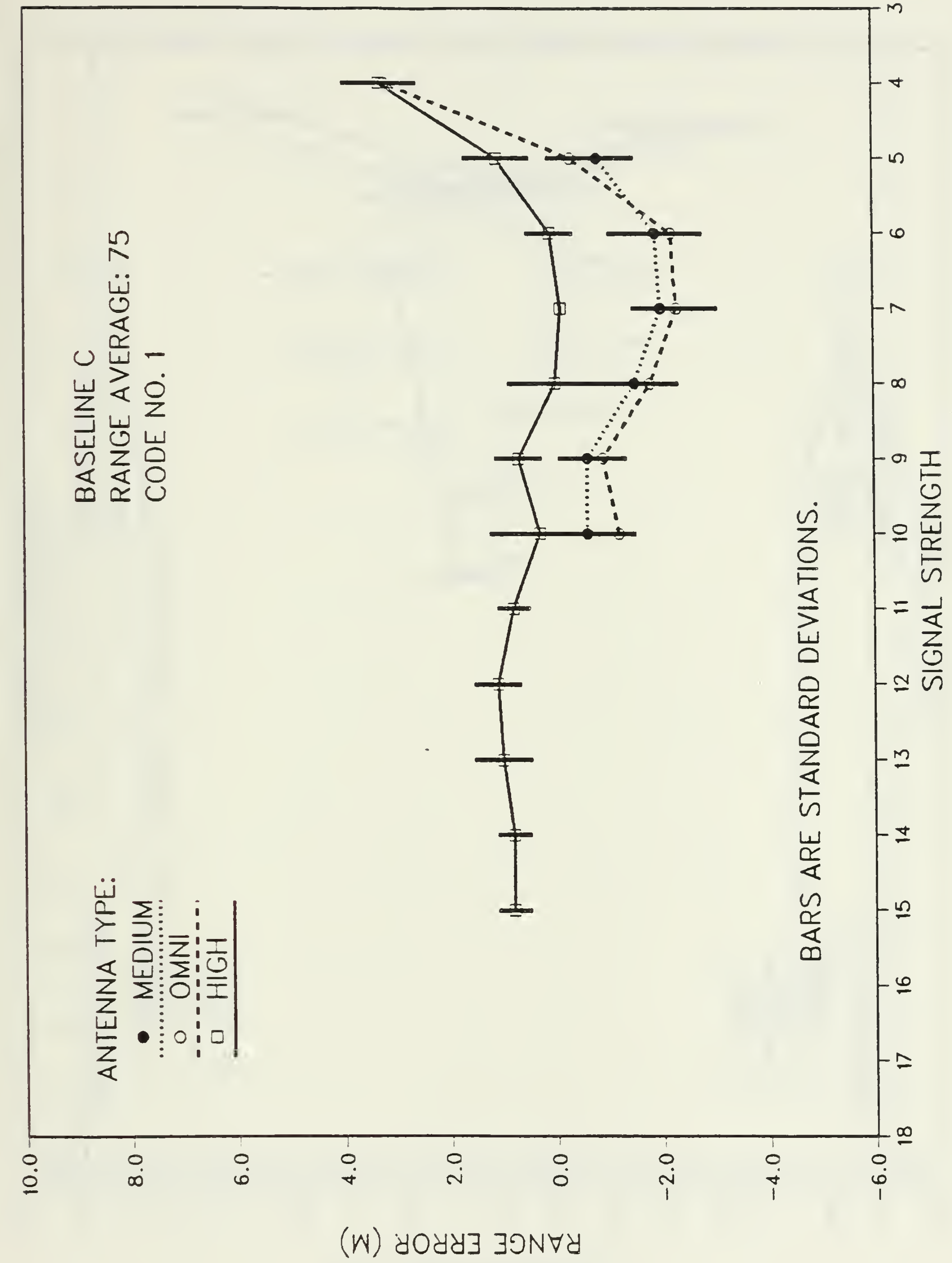

ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BASELINE B
RANGE AVERAGE: 75
CODE NO. 1
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3



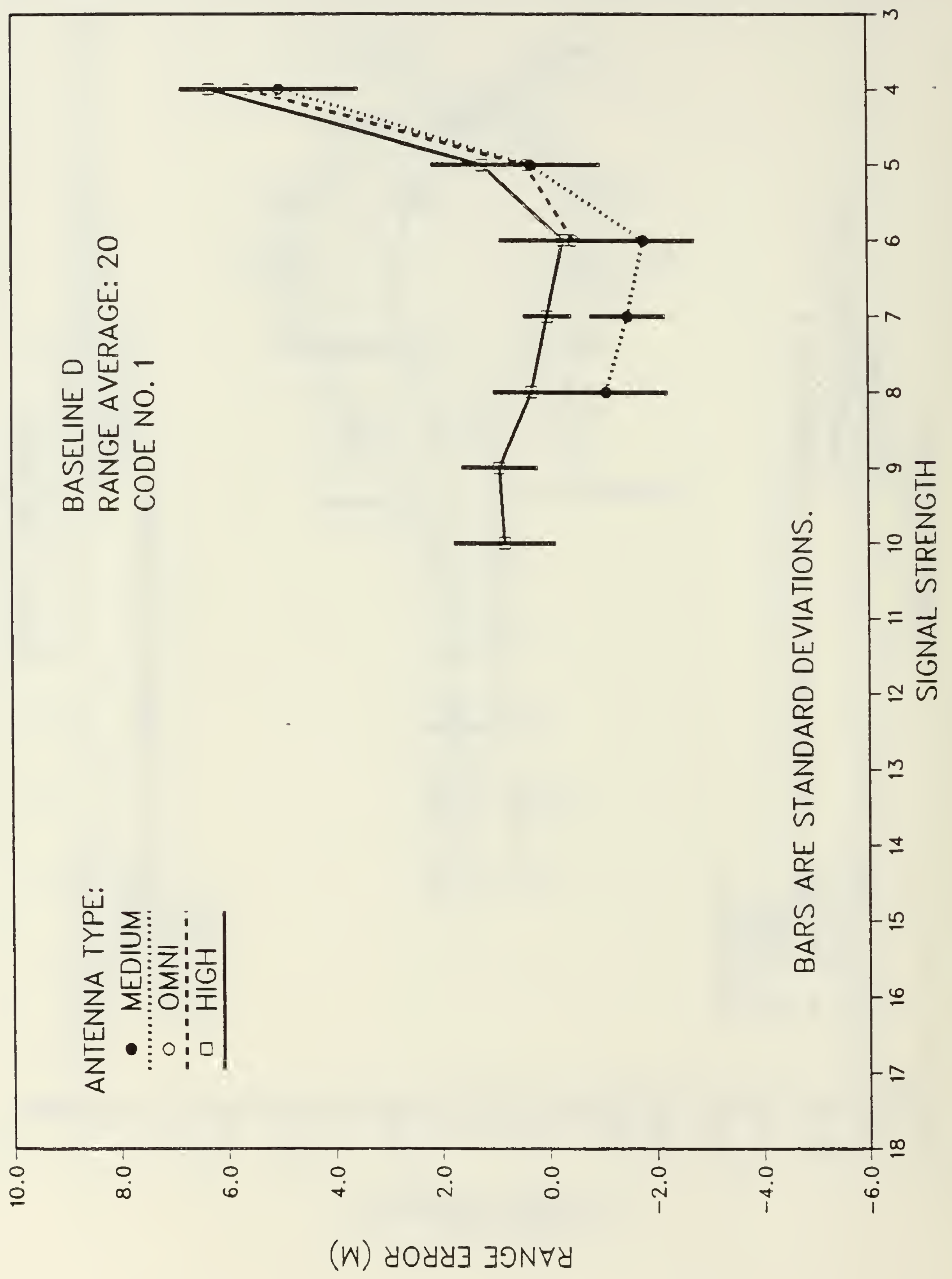
BASELINE C
RANGE AVERAGE: 20
CODE NO. 1
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
SIGNAL STRENGTH
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

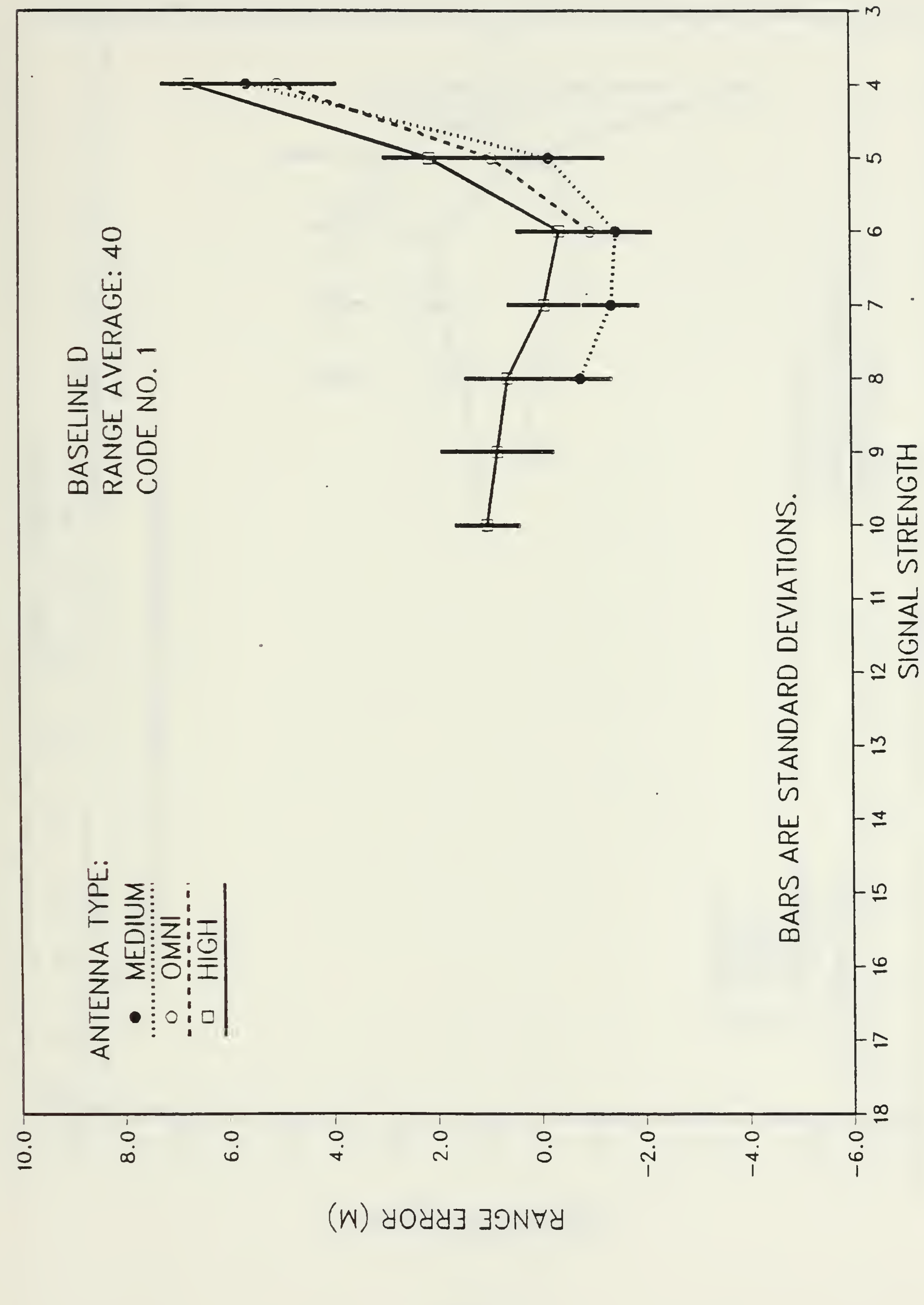


BASELINE C
RANGE AVERAGE: 40
CODE NO. 1
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

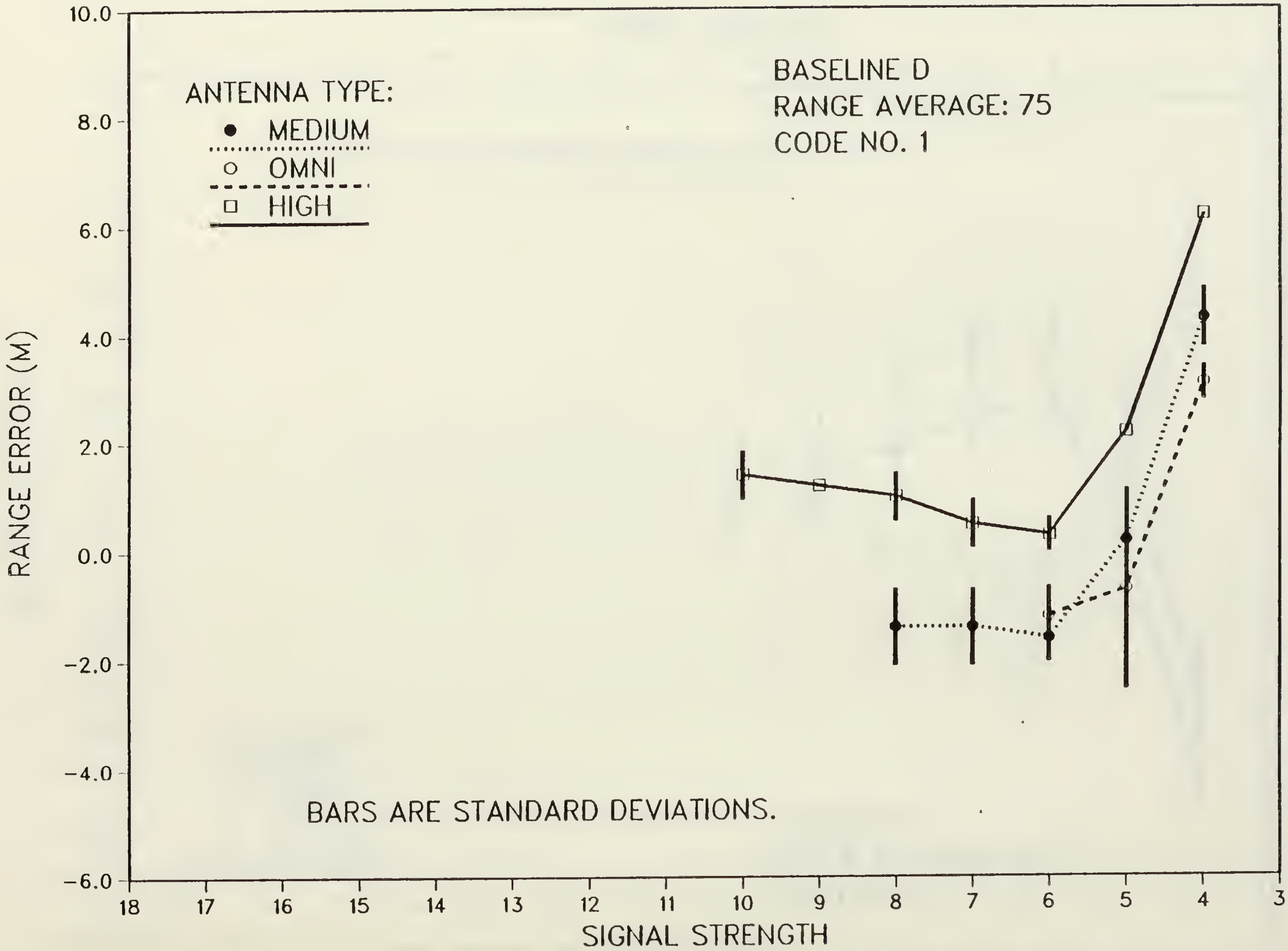


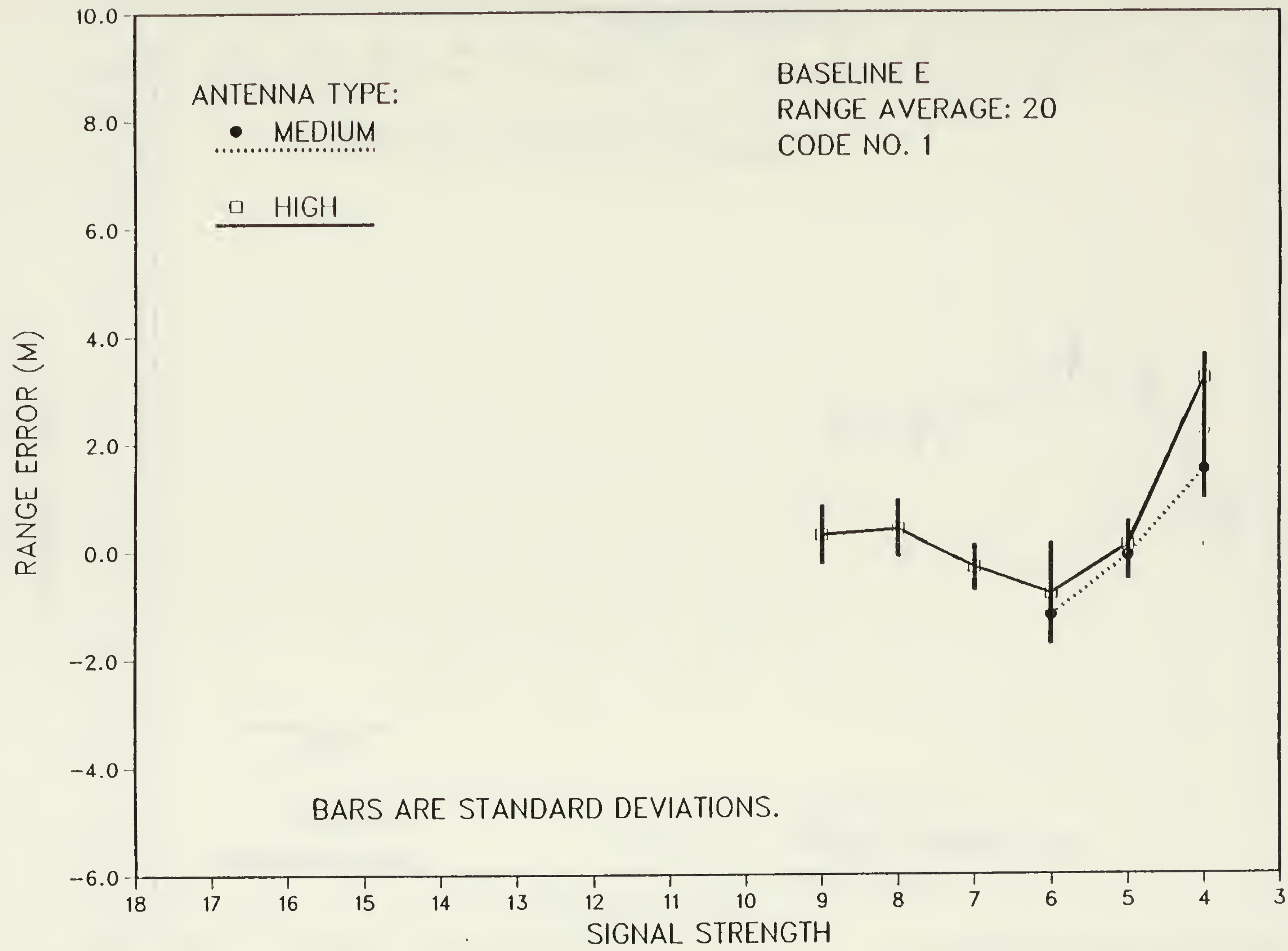
BASELINE C
RANGE AVERAGE: 75
CODE NO. 1
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
SIGNAL STRENGTH
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18


BASELINE D
RANGE AVERAGE: 20
CODE NO. 1
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

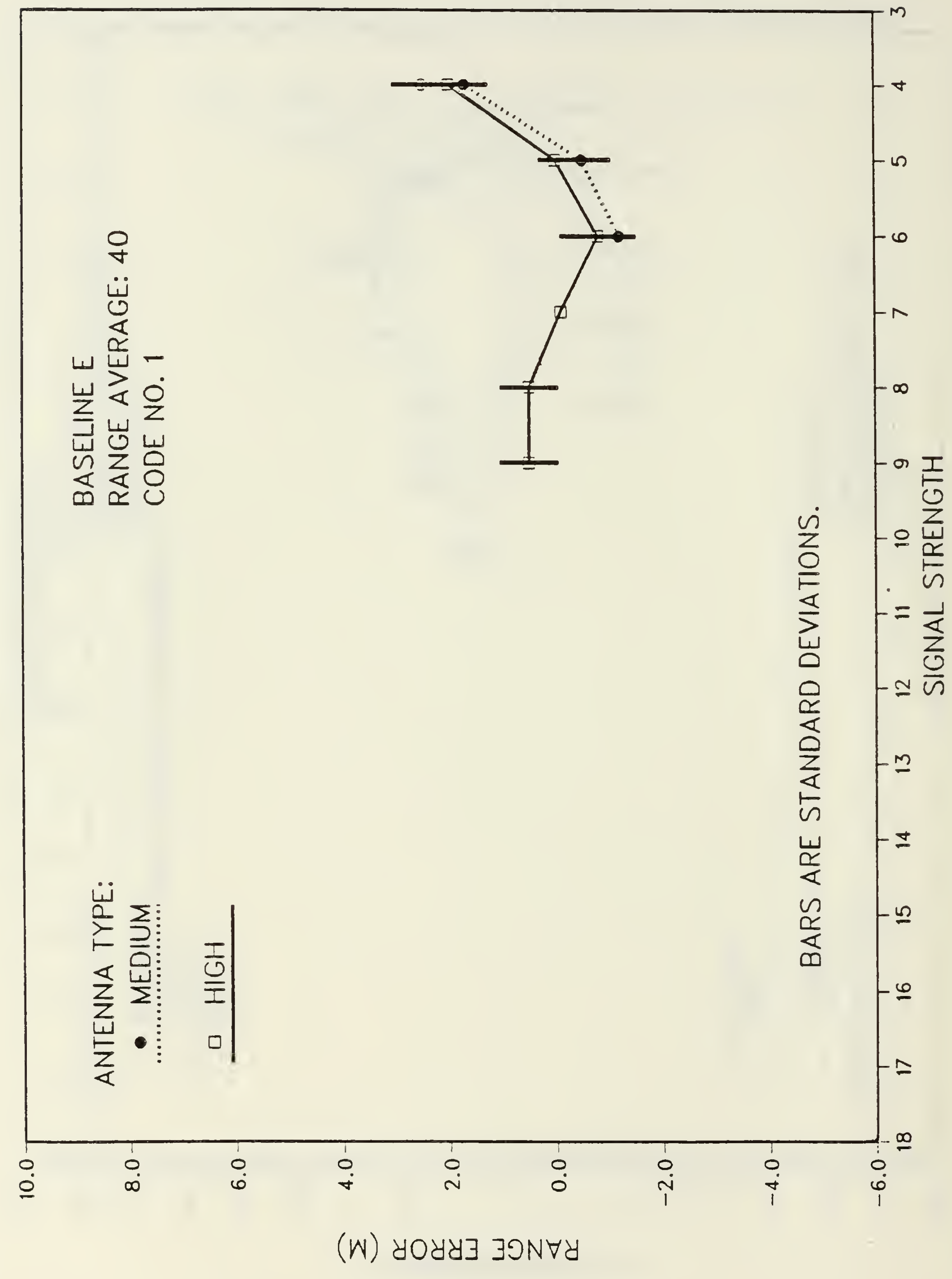


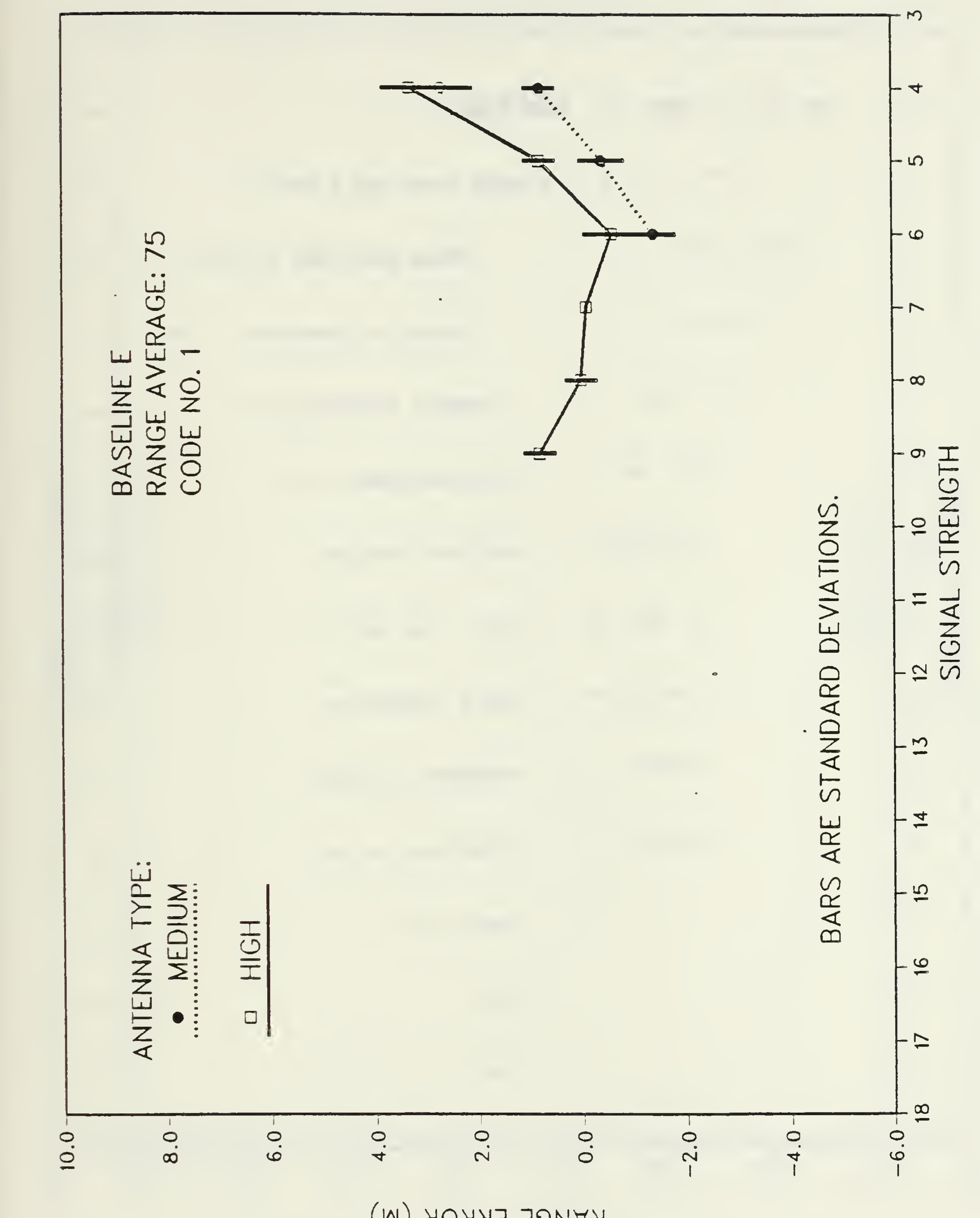
BASELINE D
RANGE AVERAGE: 40
CODE NO. 1
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

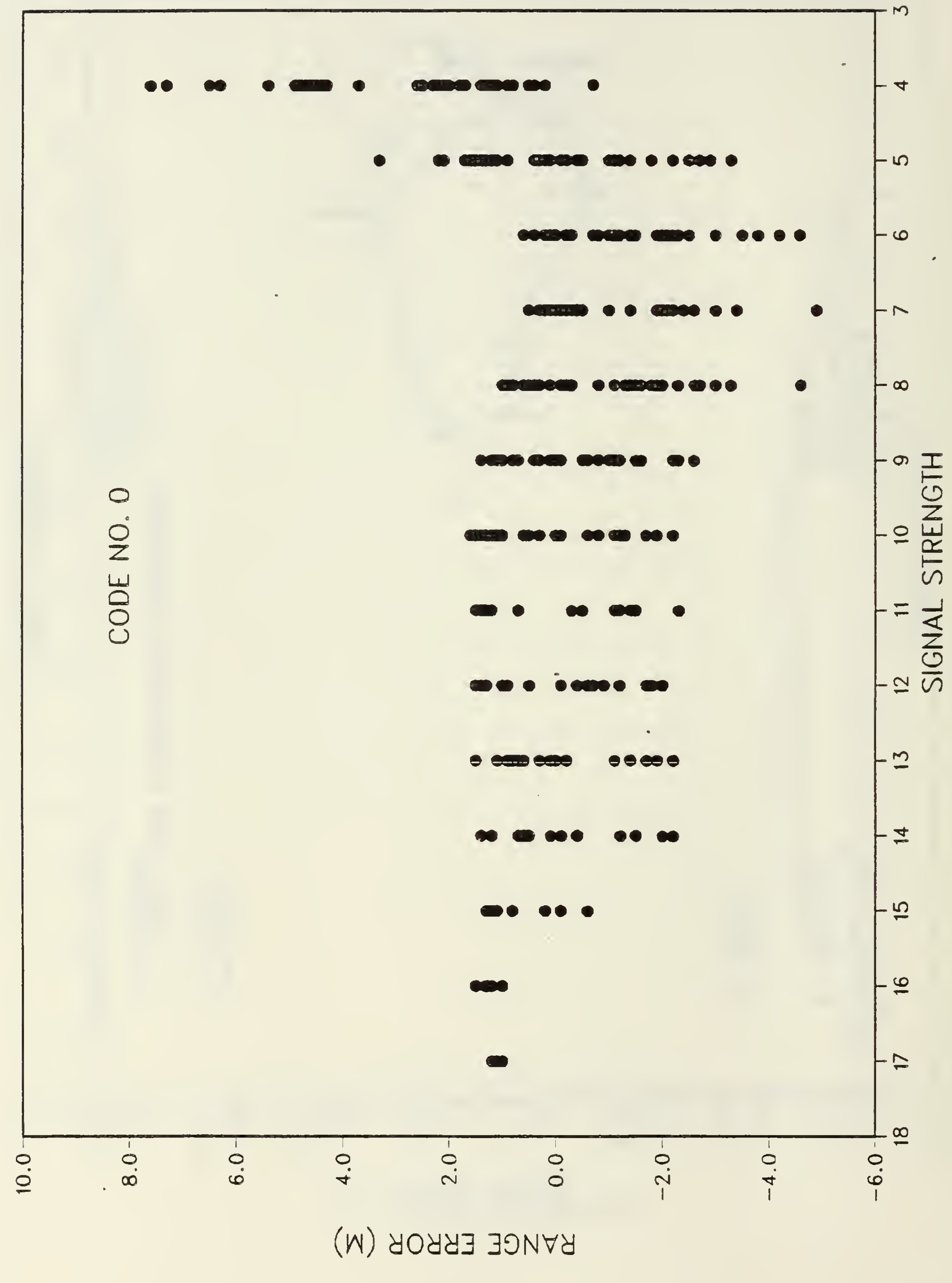

BASELINE D
RANGE AVERAGE: 75
CODE NO. 1
ANTENNA TYPE:
MEDIUM
OMNI
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3

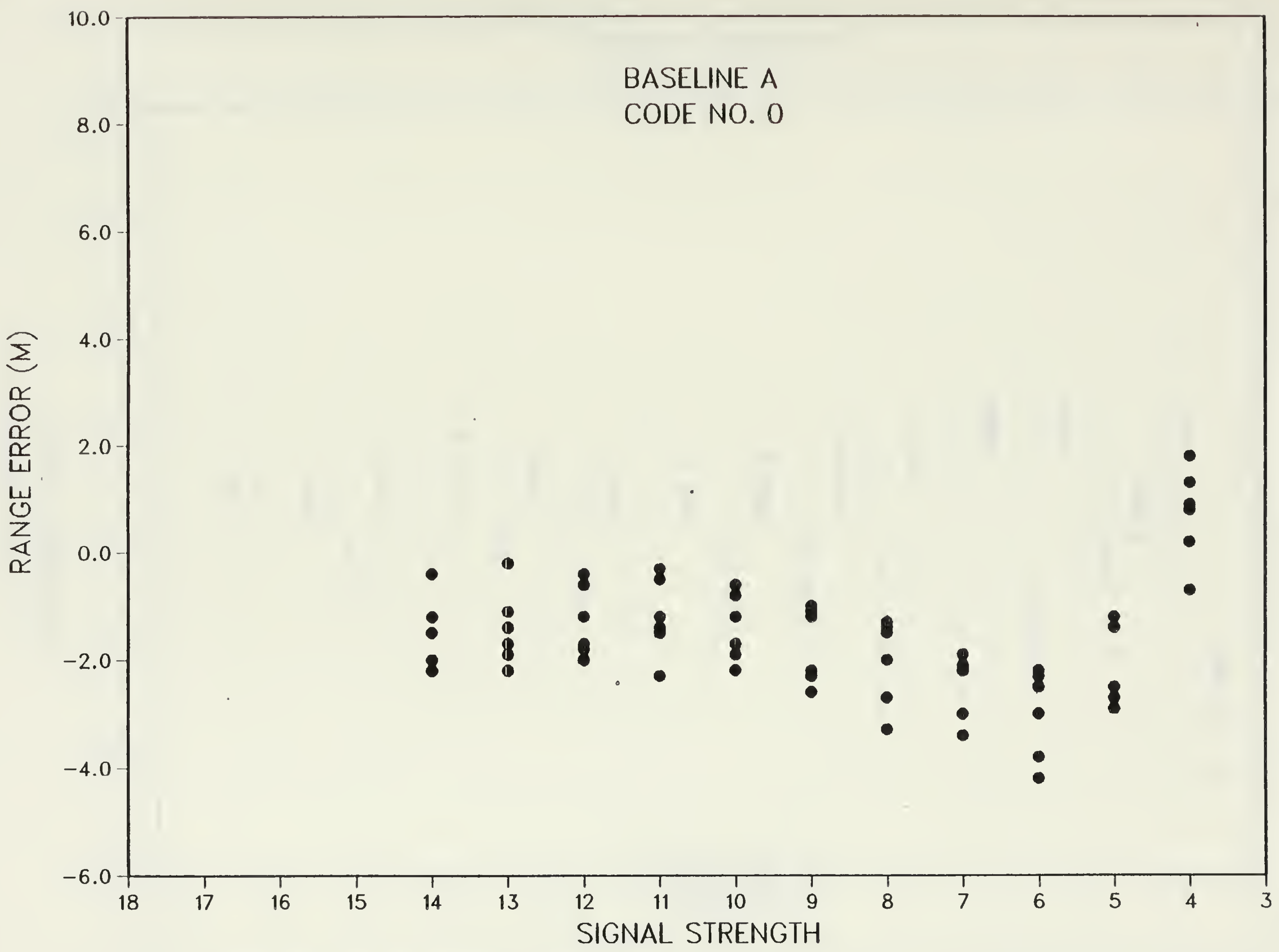


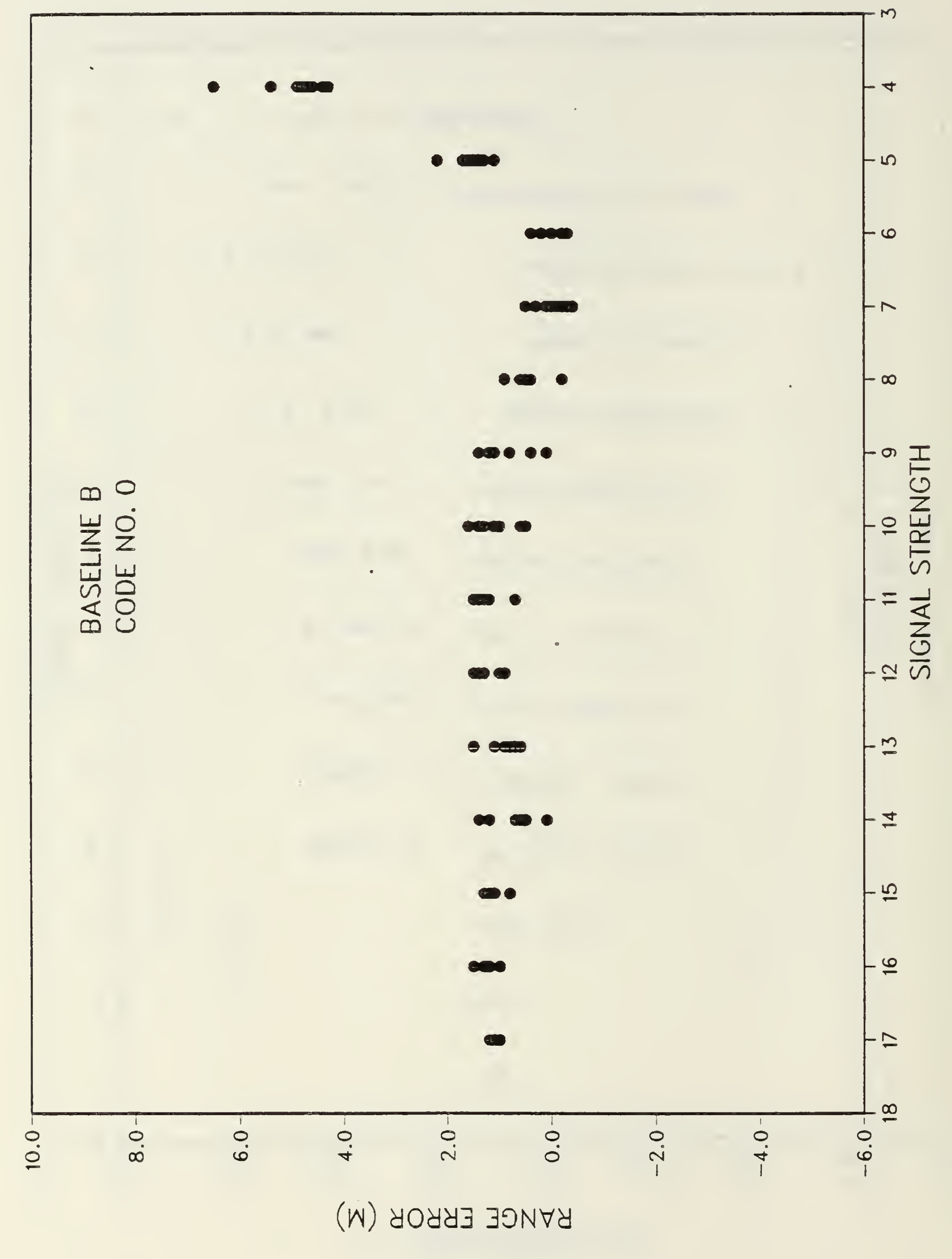
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
RANGE ERROR (M)
ANTENNA TYPE:
MEDIUM
HIGH
BASELINE E
RANGE AVERAGE: 20
CODE NO. 1
BARS ARE STANDARD DEVIATIONS.
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
SIGNAL STRENGTH


BASELINE E
RANGE AVERAGE: 40
CODE NO. 1
ANTENNA TYPE:
MEDIUM
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

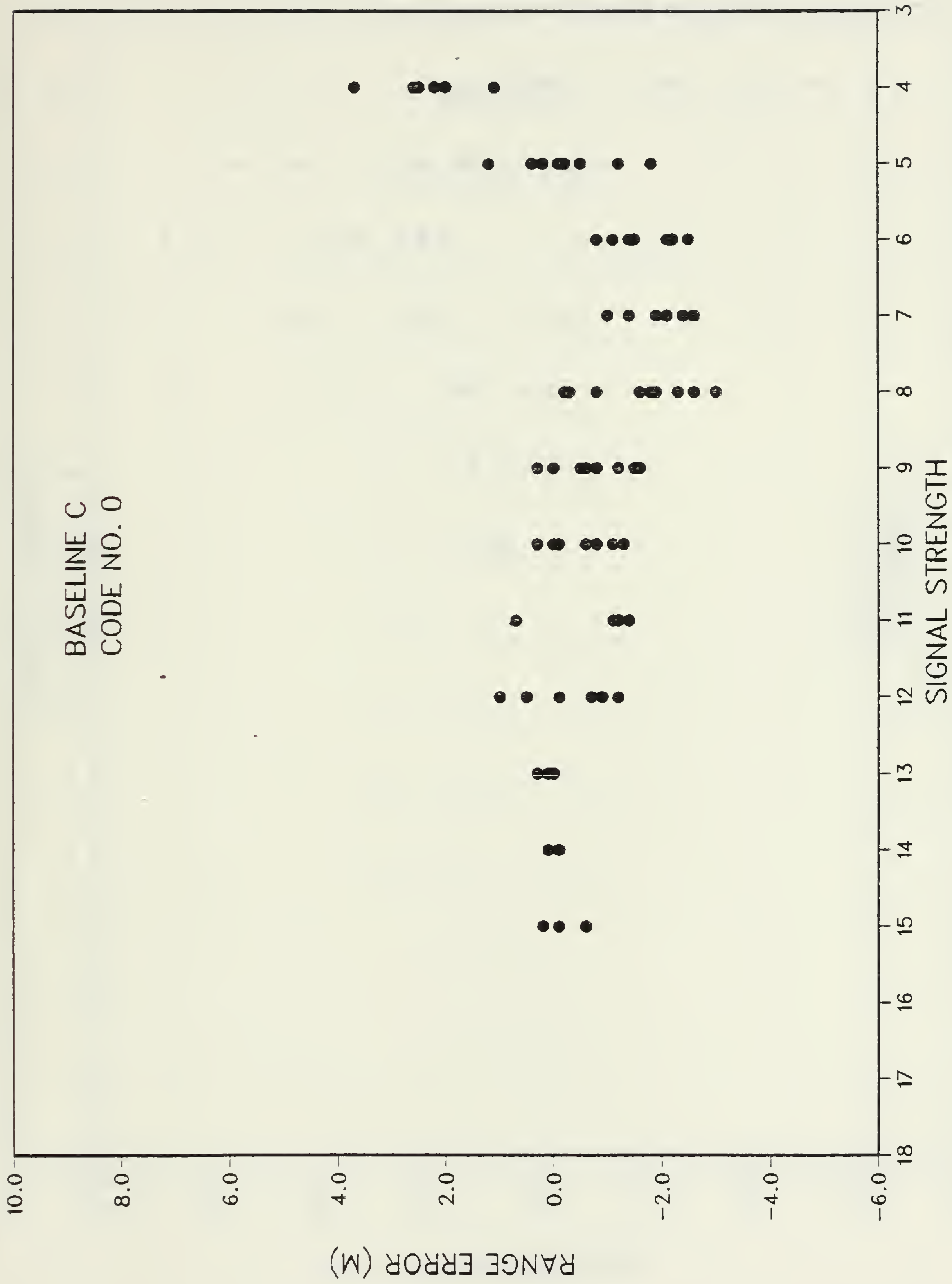

BASELINE E
RANGE AVERAGE: 75
CODE NO. 1
ANTENNA TYPE:
MEDIUM
HIGH
BARS ARE STANDARD DEVIATIONS.
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

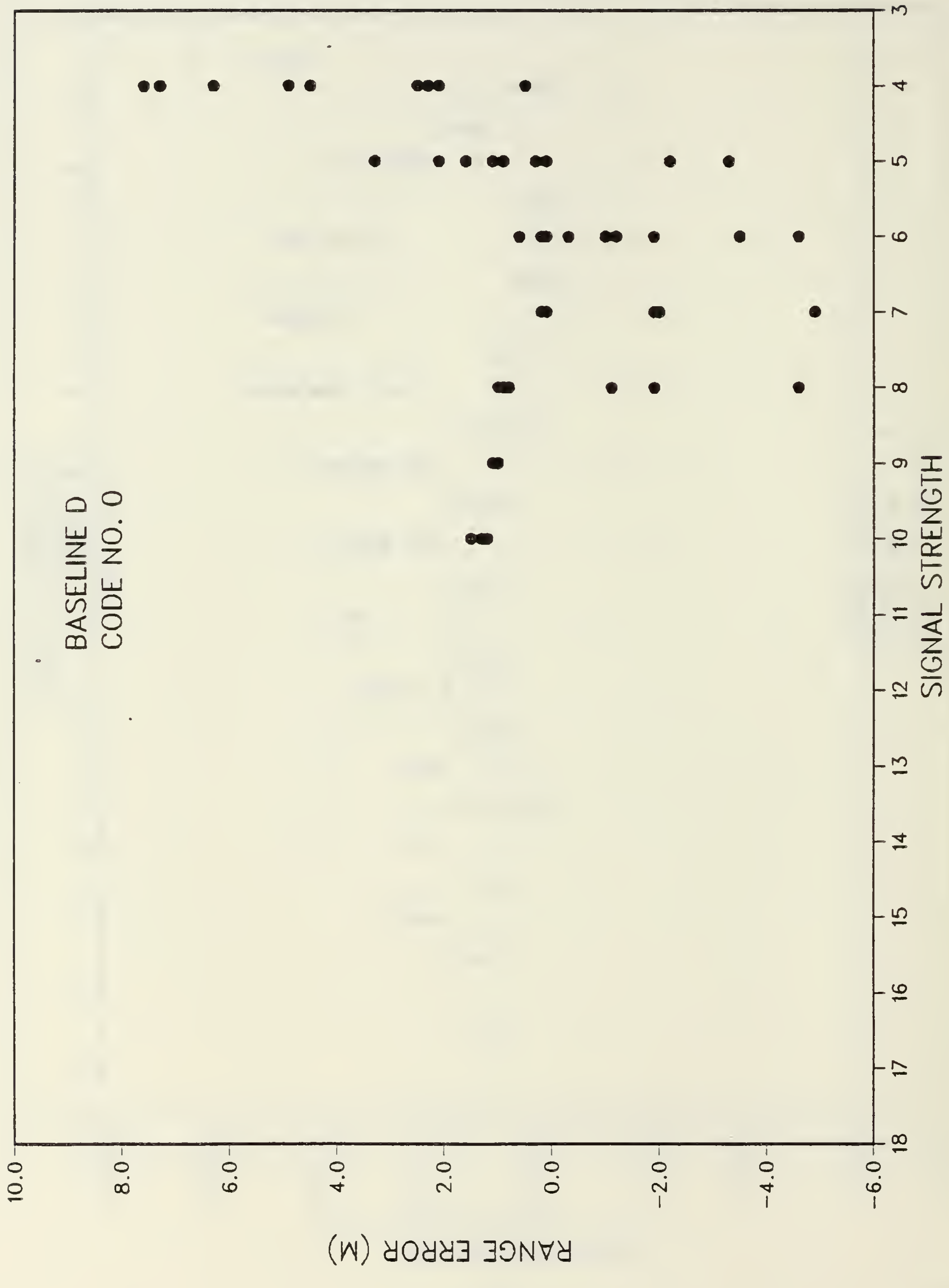

CODE NO. 0
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

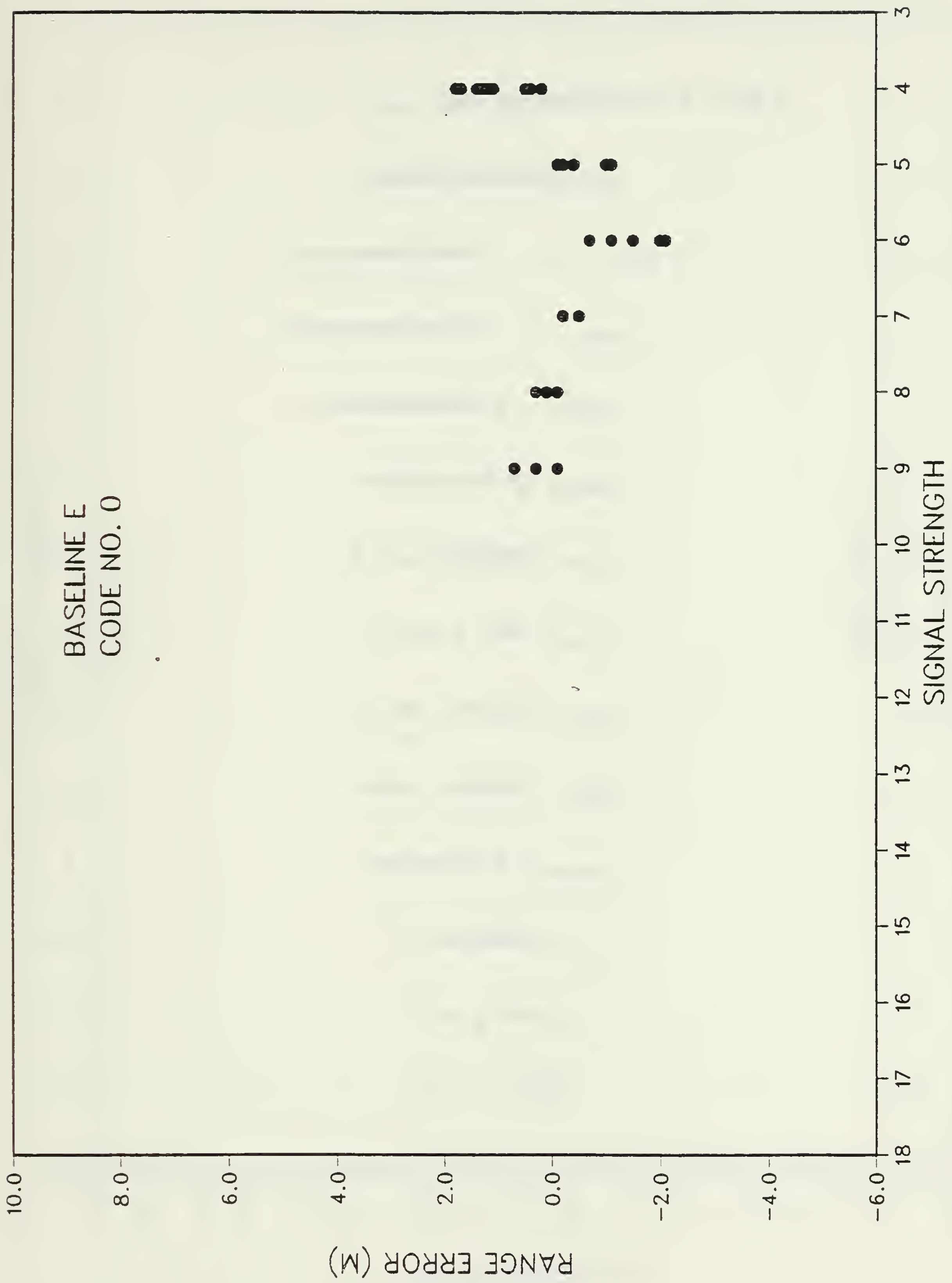

BASELINE A
CODE NO. 0
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
SIGNAL STRENGTH

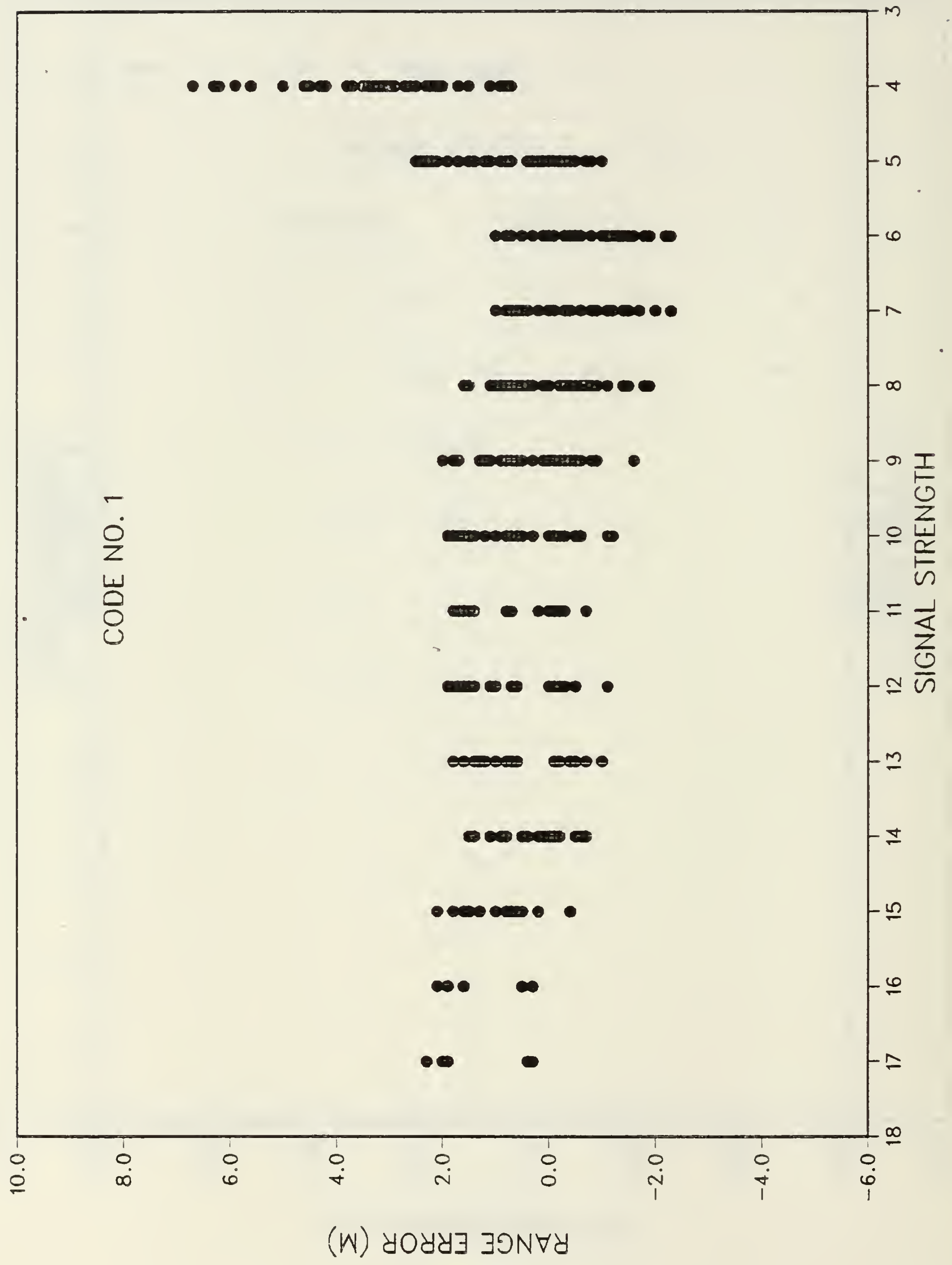


BASELINE B
CODE NO. 0
SIGNAL STRENGTH
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

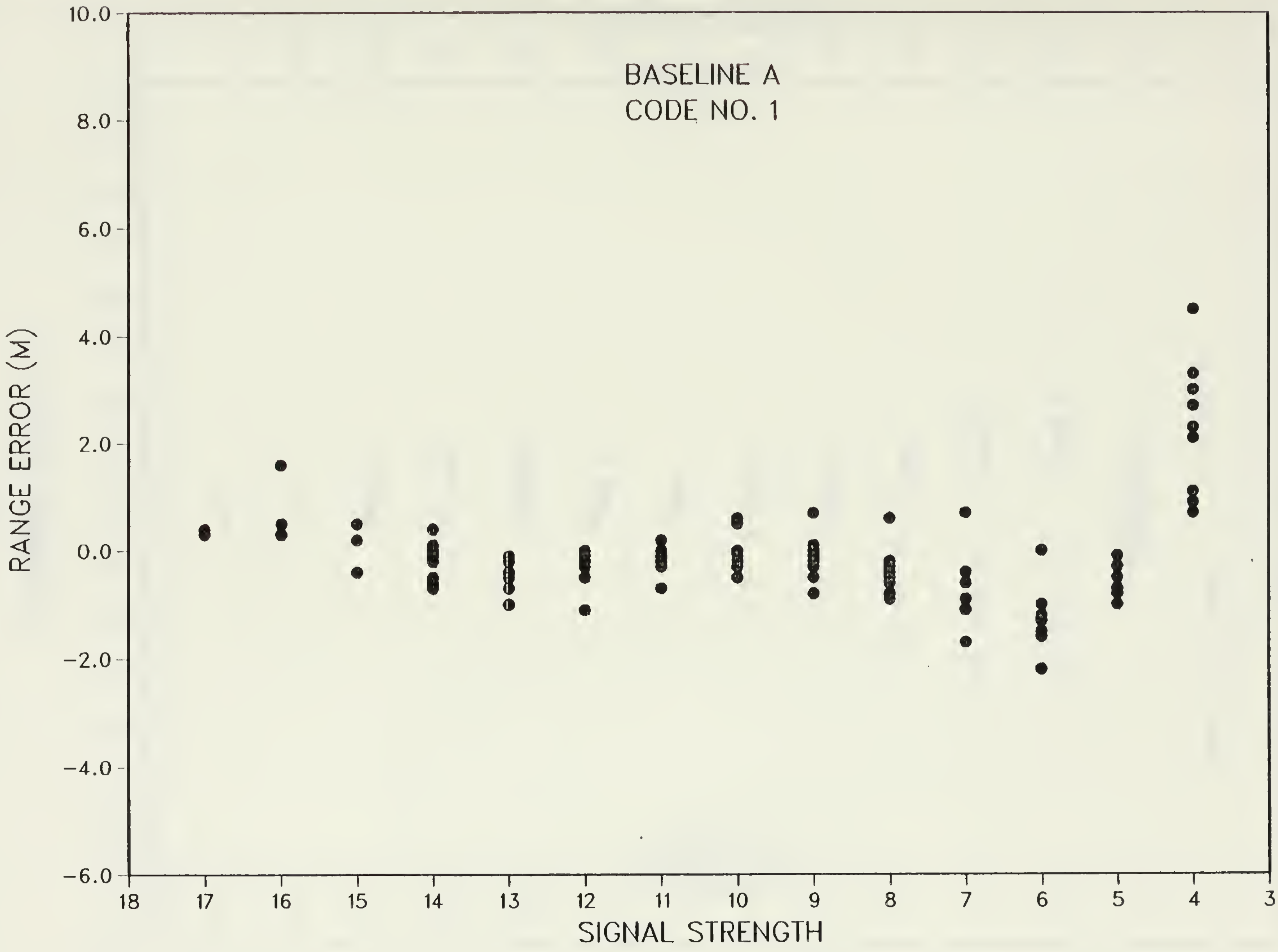

BASELINE C
CODE NO. 0
RANGE ERROR (M)
SIGNAL STRENGTH
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

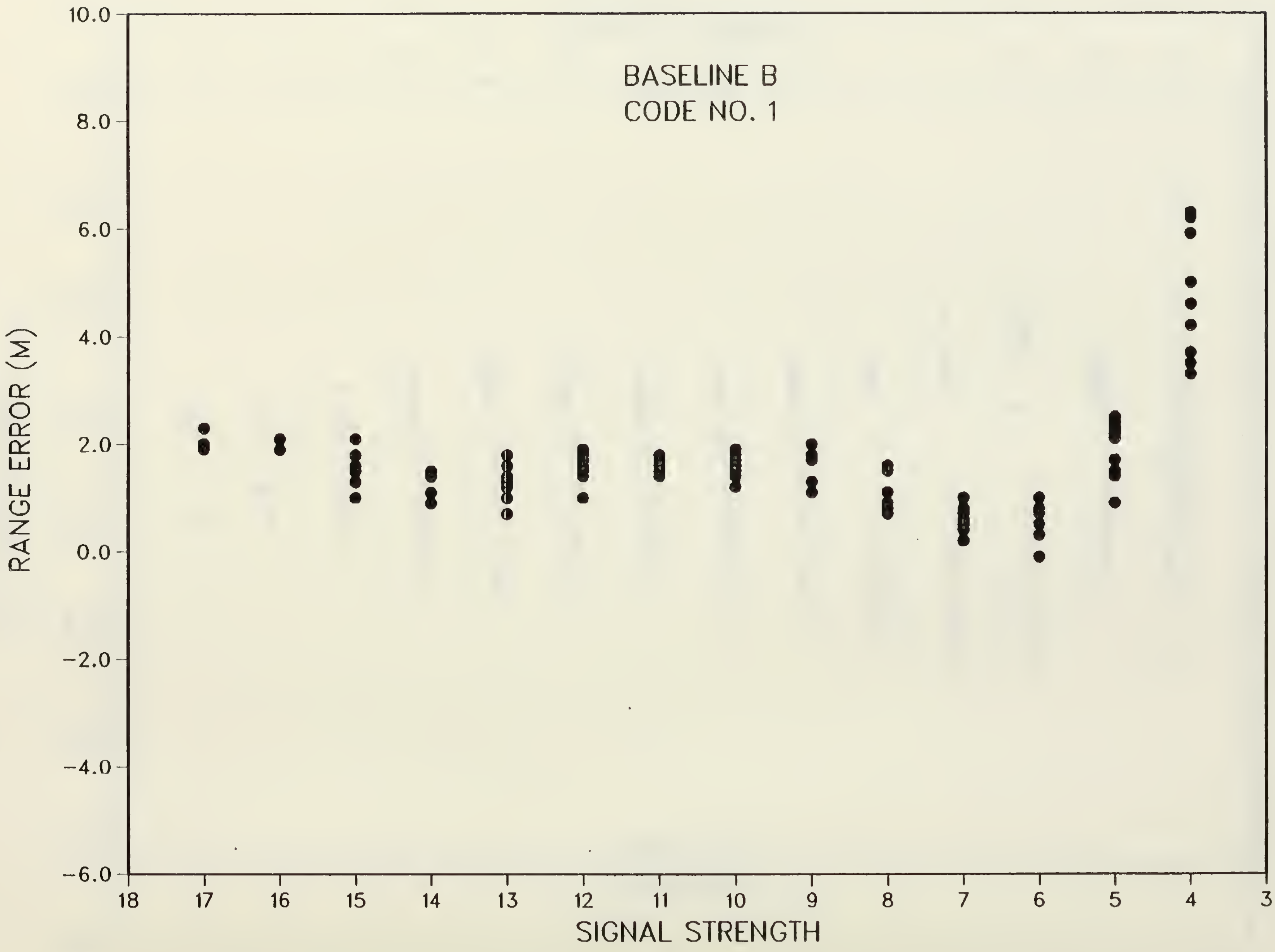

BASELINE D
CODE NO. 0
SIGNAL STRENGTH
RANGE ERROR (M)
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
10.0 8.0 6.0 4.0 2.0 0.0 -2.0 -4.0 -6.0

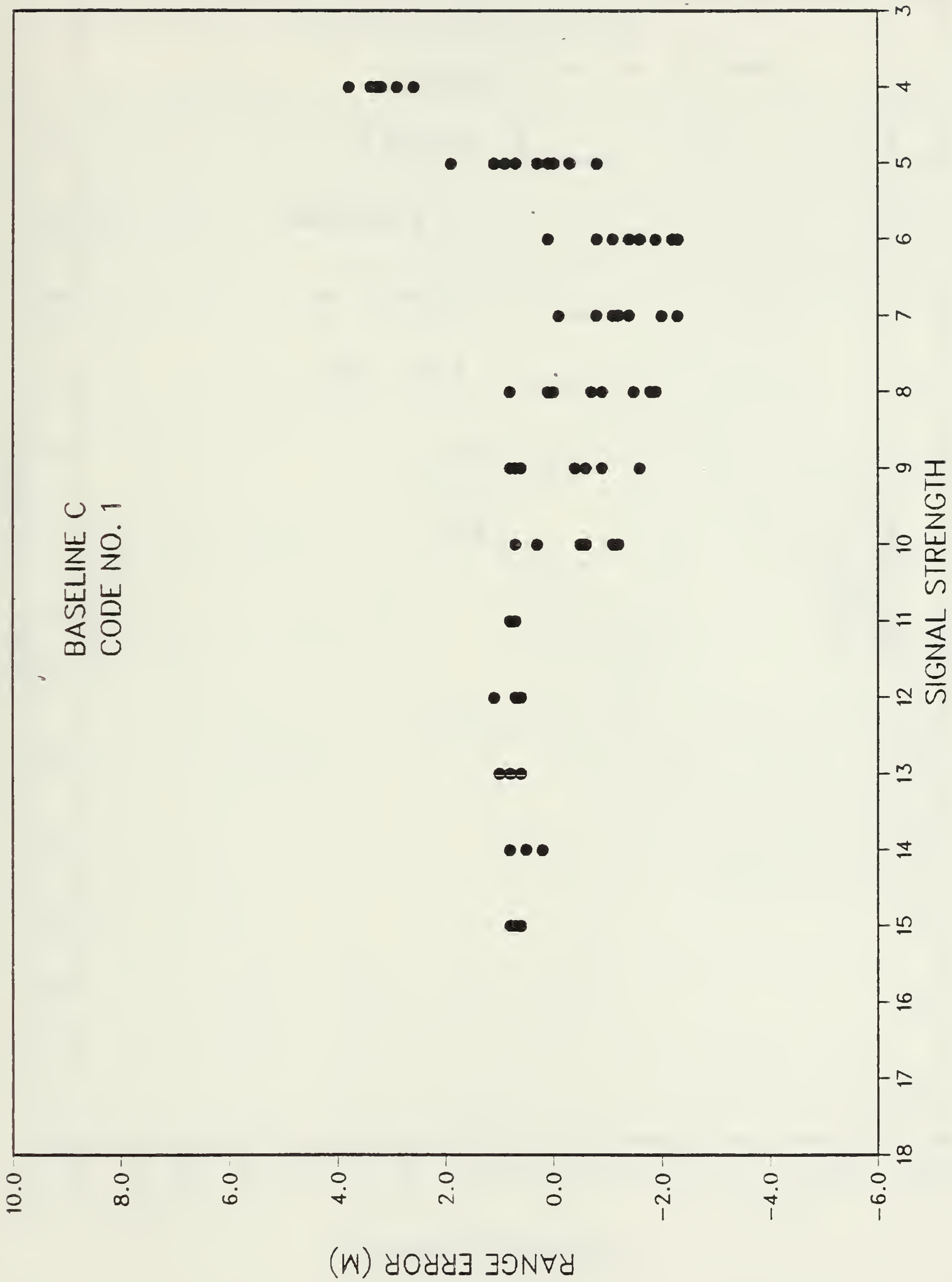

BASELINE E
CODE NO. 0
SIGNAL STRENGTH
RANGE ERROR (M)
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0

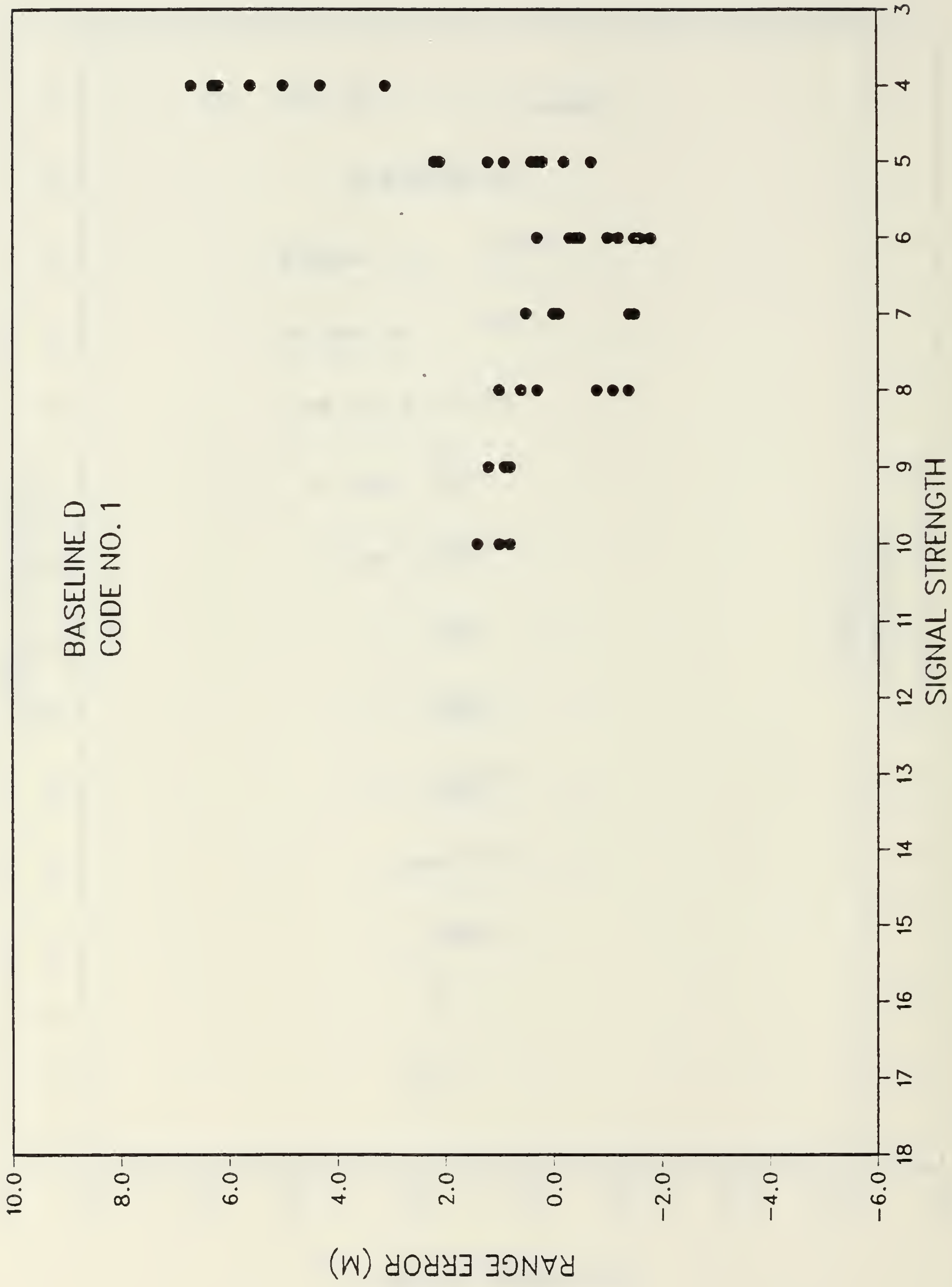


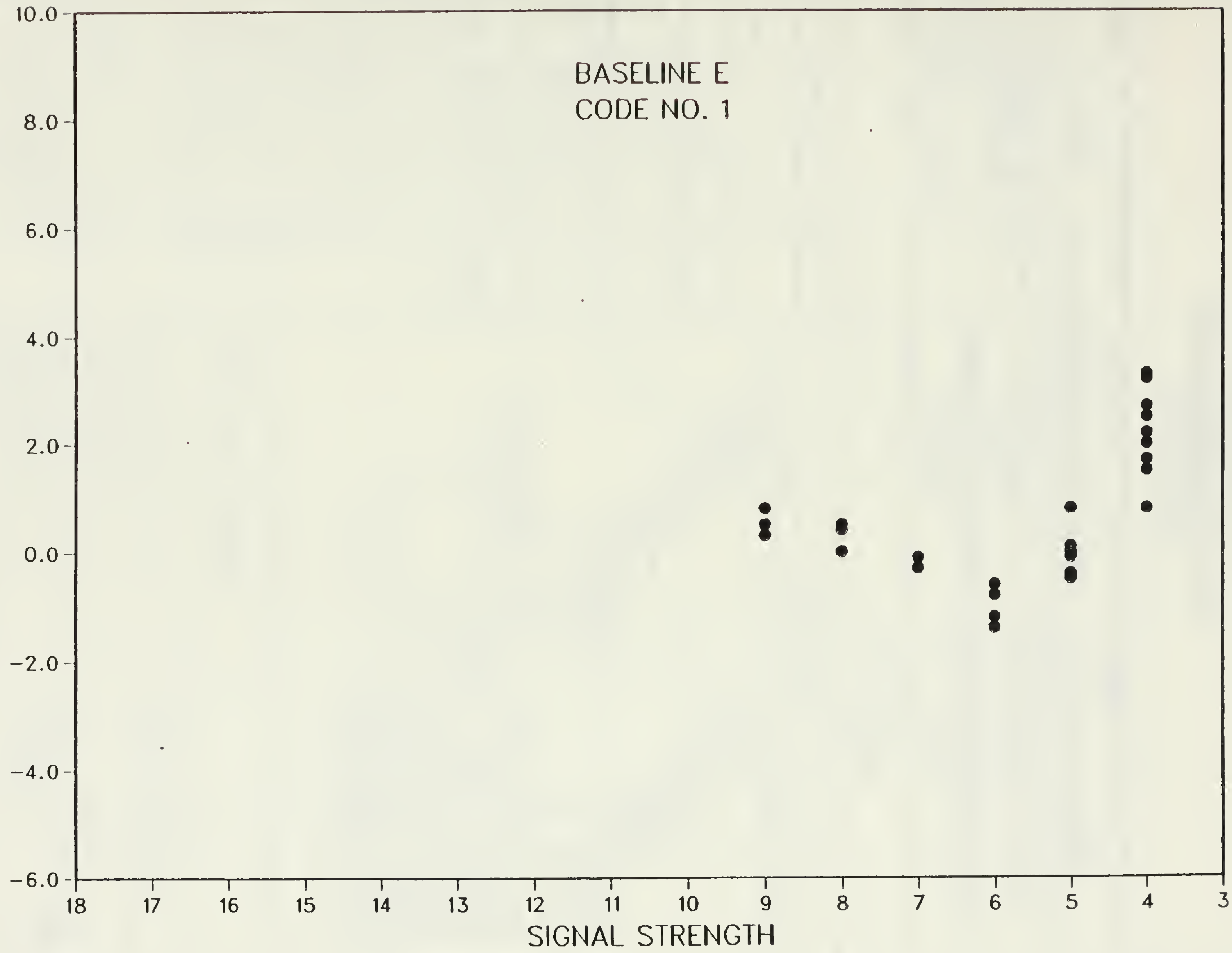
CODE NO. 1
SIGNAL STRENGTH
RANGE ERROR (M)
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0


BASELINE A
CODE NO. 1
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
SIGNAL STRENGTH


BASELINE B
CODE NO. 1
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
SIGNAL STRENGTH


BASELINE C
CODE NO. 1
SIGNAL STRENGTH
RANGE ERROR (M)
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0


BASELINE D
CODE NO. 1
SIGNAL STRENGTH
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18


BASELINE E
CODE NO. 1
RANGE ERROR (M)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
SIGNAL STRENGTH

# APPENDIX C

## TELLUROMETER DATA

The following observation forms show measurements of the five base lines obtained with the Tellurometers. All distances were corrected for meteorological effects as shown on the attached HP 9815S calculator tapes.

NOAA FORM 76-61A
(12-73)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

# TELLUROMETER OBSERVATIONS
## MODEL CA1000

| STATE | LOCALITY | DATE |
|---|---|---|
| WA. | PUGET SOUND | 29 JAN 84 |
| STATION PHEASANT BASELINE A | INST. NUMBER 1805 | HEIGHT OF INST. 1.40 |
| TO STATION WEST POINT | INST. NUMBER 1806 | HEIGHT OF INST. 1.70 |
| PROJECT NUMBER | CHIEF OF PARTY | OBSERVER BFH |

### METEOROLOGICAL DATA

| TIME | $T_{DB}$ | $T_{WB}$ | P |
|---|---|---|---|
| MASTER | 44.0 | 44.0 | 30.40 |
| REMOTE | 43.0 | 42.8 | — |
| SUM | 87.0 | 86.8 | — |
| MEAN | 43.5 | 43.4 | 30.40 |

```
PRESS= 30.400IN.
D/BULB= 43.500'F
W/BULB= 43.400'F
DIST.= 1061.245M
INS.CONS=-0.065M
REM.CONS= 0.000M
INS.OFFS= 0.000M
REM.OFFS= 0.000M

----------------
PPM=        -5.731
PPM=        -0.006
SUM OF CONSTANTS
=          -0.065M
CORR'D SLOPE
DIST= 1061.175M.
```

### FIELD READINGS

**SET 1**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| B | 0 | 3 | | | | | |
| C | | 3 | 4 | | | | |
| D | | | 4 | 8 | | | |
| E | | | | 8 | 1 | | |
| A | | | | | 1 | 5 | 8 |
| | | | | | 1. | 6 | 0 |
| | 0 | 3 | 4 | 8 | 1 | 5 | 9 |

**SET 2**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| B | 0 | 3 | | | | | |
| C | | 3 | 4 | | | | |
| D | | | 4 | 8 | | | |
| E | | | | 8 | 1 | | |
| A | | | | | 1 | 0 | 3 |
| | | | | | 1: | 1 | 3 |
| | | | | | 1: | 2 | 3 |
| | 0 | 3 | 4 | 8 | 1 | 1 | 3 |
| Set back/ahead | | | + | | | 8 | 2 |
| Slope distance | 0 | 3 | 4 | 8 | 1 | 9 | 5 |
| | 0 | 3 | 4 | 8 | 1 | 5 | 9 FT. |
| MEAN SETS 1 & 2 = | 0 | 3 | 4 | 8 | 1 | 7 | 7 FT. |

METERS FEET X 0.3048006096

| | |
|---|---|
| DISTANCE (*Meters*) | 1061.246 m |
| METEOROLOGICAL CORRECTION | -0.006 |
| FIXED INSTRUMENT CORRECTION | -0.065 |
| CORRECTED SLOPE DISTANCE | 1061.175 m. |

F4

NOAA FORM 76-61A
(12-73)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

# TELLUROMETER OBSERVATIONS
## MODEL CA1000

| | | |
|---|---|---|
| STATE WA. | LOCALITY PUGET SOUND | DATE 29 JAN 84 |
| STATION (SHILSHOLE PIER) BASELINE B | INST. NUMBER 1806 | HEIGHT OF INST. 1.46 m |
| TO STATION WEST POINT | INST. NUMBER 1805 | HEIGHT OF INST. 1.77 m |
| PROJECT NUMBER | CHIEF OF PARTY | OBSERVER RLH |

**METEOROLOGICAL DATA**

| TIME | $T_{DB}$ | $T_{WB}$ | P |
|---|---|---|---|
| MASTER | 47.0 | 45.0 | 30.45 |
| REMOTE | 45.5 | 45.0 | 30.30 |
| SUM | 92.5 | 90.0 | 60.75 |
| MEAN | 46.2 | 45.0 | 30.37 |

```
PRESS= 30.370IN.
D/BULB= 46.200'F
W/BULB= 45.000'F
DIST.= 2417.492M
INS.CONS=-0.004M
REM.CONS= 0.000M
INS.OFFS= 0.000M
REM.OFFS= 0.000M
----------------
PPM=       -4.373
PPM=       -0.011
SUM OF CONSTANTS
=         -0.004M
CORR'D SLOPE
DIST= 2417.477M.
```

**FIELD READINGS**

| | SET 1 | SET 2 |
|---|---|---|
| B | 07 | 07 |
| C | 79 | 79 |
| D | 93 | 93 |
| E | 31 | 30 |
| A | 150 / 152 | 045 / 045 |
| | 0793151 | 0793045 |

Set back / ahead ⊕ 082

Slope distance 0793127

0793151 FT.

MEAN SETS 1 & 2 = 0793139 FT.

METERS    FEET X 0.3048006096

| | |
|---|---|
| DISTANCE (Meters) | 2417.492 |
| METEOROLOGICAL CORRECTION | -0.011 |
| FIXED INSTRUMENT CORRECTION | -0.004 m |
| CORRECTED SLOPE DISTANCE | 2417.477 m. |

F3

NOAA FORM 76-61A (12-73)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

# TELLUROMETER OBSERVATIONS
## MODEL CA1000

| STATE | LOCALITY | DATE |
|---|---|---|
| WA. | PUGET SOUND | 28 JAN. 84 |
| STATION (MEADOW PT.) BASELINE C | INST. NUMBER 1806 | HEIGHT OF INST. 0.85 m |
| TO STATION WEST POINT | INST. NUMBER 1805 | HEIGHT OF INST. 1.77 m |
| PROJECT NUMBER | CHIEF OF PARTY | OBSERVER RLH |

**METEOROLOGICAL DATA**

| TIME | $T_{DB}$ | $T_{WB}$ | P |
|---|---|---|---|
| MASTER | 47.0 | 47.0 | 30.35 |
| REMOTE | 47.0 | 47.0 | 30.33 |
| SUM | 94.0 | 94.0 | 60.68 |
| MEAN | 47.0 | 47.0 | 30.34 |

```
PRESS= 30.340IN.
D BULB= 47.000'F
W BULB= 47.000'F
DIST.= 4083.139M
INS.CONS=-0.004M
REM.CONS= 0.000M
INS.OFFS= 0.000M
REM.OFFS= 0.000M
-----------------
PPM=        -9.327
PPM=        -0.038
SUM OF CONSTANTS
=          -0.004M
CORR'D SLOPE
DIST= 4083.097M.
```

**FIELD READINGS**

| | SET 1 | SET 2 |
|---|---|---|
| B | 13 | 13 |
| C | 33 | 33 |
| D | 39 | 39 |
| E | 96 | 95 |
| A | 6.07 | 5.27 |
| | 612 | 531 |
| | 13396.10 | 13395.29 |

Set back/ahead: + 0.82

Slope distance: 13396.11

13396.10 FT.

MEAN SETS 1 & 2 = 13396.10 FT.

METERS FEET X 0.3048006096

| | |
|---|---|
| DISTANCE (Meters) | 4083.139 m |
| METEOROLOGICAL CORRECTION | −0.038 |
| FIXED INSTRUMENT CORRECTION | −0.004 m F(3) |
| CORRECTED SLOPE DISTANCE | 4083.097 m. |

NOAA FORM 76-61A
(12-73)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

# TELLUROMETER OBSERVATIONS
## MODEL CA1000

| STATE | LOCALITY | DATE |
|---|---|---|
| WA. | PUGET SOUND | 28 JAN. 84 |
| STATION (LITTLEFOOT) BASELINE D | INST. NUMBER 1806 | HEIGHT OF INST. 1.25 m |
| TO STATION WEST POINT | INST. NUMBER 1805 | HEIGHT OF INST. 1.77 m |
| PROJECT NUMBER | CHIEF OF PARTY | OBSERVER RLH |

**METEOROLOGICAL DATA**

| TIME | $T_{DB}$ | $T_{WB}$ | P |
|---|---|---|---|
| MASTER | 50.0 | 49.0 | 30.45 |
| REMOTE | 48.0 | 47.5 | 30.36 |
| SUM | 98.0 | 96.5 | 60.81 |
| MEAN | 49.0 | 48.2 | 30.40 |

```
PRESS= 30.400IN.
D/BULB= 49.000'F
W/BULB= 48.200'F
DIST.= 7016.839M
INS.CONS=-0.004M
REM.CONS= 0.000M
INS.OFFS= 0.000M
REM.OFFS= 0.000M

----------------
PPM=        -9.313
PPM=        -0.065
SUM OF CONSTANTS
=          -0.004M
CORR'D SLOPE
DIST= 7016.770M.
```

**FIELD READINGS**

| | SET 1 | SET 2 |
|---|---|---|
| B | 23 | 23 |
| C | 30 | 30 |
| D | 02 | 02 |
| E | 21 | 20 |
| A | 110 (109) | 025 (0.25) |
| | 2302110 | 2302025 |
| Set back, ahead | | + 082 |
| Slope distance | | 2302107 |
| | | 2302110 FT. |
| MEAN SETS 1 & 2 = | | 2302108 FT. |

METERS FEET X 0.3048006096

| | |
|---|---|
| DISTANCE (Meters) | 7016.839 m |
| METEOROLOGICAL CORRECTION | −0.065 |
| FIXED INSTRUMENT CORRECTION | −0.004 m F③ |
| CORRECTED SLOPE DISTANCE | 7016.770 m. |

NOAA FORM 76-61A
(12-73)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

# TELLUROMETER OBSERVATIONS
## MODEL CA1000

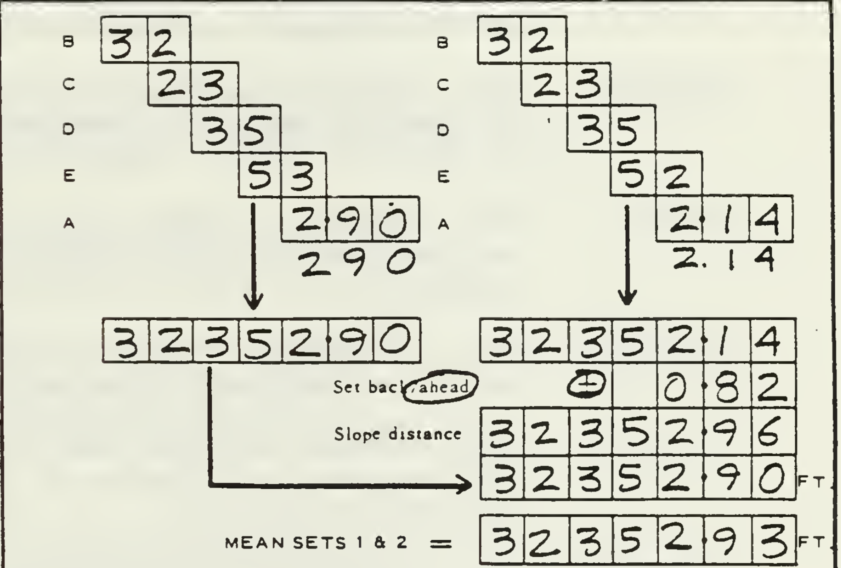
| | | |
|---|---|---|
| STATE<br>WA. | LOCALITY<br>PUGET SOUND | DATE<br>28 JAN 84 |
| STATION<br>(FT. JEFFERSON) BASELINE E | INST. NUMBER<br>1806 | HEIGHT OF INST.<br>1.25 m |
| TO STATION<br>WEST POINT | INST. NUMBER<br>1805 | HEIGHT OF INST.<br>1.77 m |
| PROJECT NUMBER | CHIEF OF PARTY | OBSERVER<br>RLH |

**METEOROLOGICAL DATA**

| TIME | $T_{DB}$ | $T_{WB}$ | P |
|---|---|---|---|
| MASTER | 53.0 | 51.0 | 30.40 |
| REMOTE | 49.5 | 49.5 | 30.32 |
| SUM | 102.5 | 100.5 | 60.72 |
| MEAN | 51.2 | 50.2 | 30.36 |

```
PRESS= 30.360IN.
D/BULB= 51.200'F
W/BULB= 50.200'F
DIST.= 9861.193M
INS.CONS=-0.004M
REM.CONS= 0.000M
INS.OFFS= 0.000M
REM.OFFS= 0.000M
-----------------
PPM=        -11.007
PPM=        -0.109
SUM OF CONSTANTS
=           -0.004M
CORR'D SLOPE
DIST= 9861.080M.
```

**FIELD READINGS**




METERS  FEET X 0.3048006096

| | |
|---|---|
| DISTANCE (Meters) | 9861.193 m |
| METEOROLOGICAL CORRECTION | - 0.109 |
| FIXED INSTRUMENT CORRECTION | -0.004 m  F③ |
| CORRECTED SLOPE DISTANCE | 9861.080 m. |

## APPENDIX D

## COMPUTER PROGRAMS


| Program | Description | Page |
|---|---|---|
| METOBS | Uses DISSPLA subroutines to generate plots of temperature and barometric pressure versus time. | 121 |
| RAWRITE | Reads Mini-Ranger rates from a file; corrects the rates for a 16-meter offset; and writes the corrected rates, header information, and signal strengths to another file. | 123 |
| STAT | Lists the means and variances of both observed rates and computed range errors of Mini-Ranger calibration data. | 125 |
| SSPLOT | Uses DISSPLA subroutines to generate plots of mean range error (and standard deviation) versus signal strength. | 128 |
| WALK | Uses DISSPLA subroutines to generate plots of mean range error versus base-line distance. | 132 |
| POLYFIT | Fits polynomial curves for up to degree seven to the mean range error values. | 137 |
| POLY | Uses DISSPLA subroutines to generate plots of range errors predicted from polynomial regression curves. | 140 |
| BASELINE | Uses DISSPLA subroutines to generate plots of range error versus signal strength for each base line. | 143 |

```
C
C ************************************************************************
C
C         PROGRAM:  METEOROLOGICAL OBSERVATIONS VS TIME (IN HRS.)
C         AUTHOR:   BRUCE F. HILLARD
C         DATE:     APRIL 1984
C         PROGRAM DESCRIPTION:  THIS FORTRAN PROGRAM USES DISSPLA
C                               SUBROUTINES TO GENERATE PLOTS OF
C                               TEMPERATURE AND BAROMETRIC PRESSURE
C                               VERSUS HOURS.
C         INPUT:    INPUT COMES FROM DATA STATEMENTS.
C
C         OUTPUT:   THE RESULTANT PLOT CAN BE DIRECTED TO ONE OF THREE
C                   PLOTTERS: VERSATEC 8222A, VERSATEC 0900A, OR A
C                   TEKTRONIX 4631 HARDWARE DEVICE.
C
C************************************************************************
C
C
      REAL TEMP,PRESS,TIME
      DIMENSION TEMP(50),PRESS(50),IPAK(100),TIME(50)
C
C ********** JAN. 27 DATA
C
      DATA TIME/0400.,0700.,1000.,1300.,1600.,1900.,2200./
      DATA TEMP/47.0,48.0,49.0,50.0,51.0,50.0,50.0/
      DATA PRESS/30.43,30.40,30.42,30.43,30.40,30.44,30.44/
C
C ********** JAN.28 DATA
C
C     DATA TIME/0400.,1000.,1300.,1600.,1900.,2200./
C     DATA TEMP/49.0,48.0,52.0,52.0,50.0,50.0/
C     DATA PRESS/30.48,30.46,30.44,30.38,30.40,30.40/
C
C ********** JAN. 29 DATA
C
C     DATA TIME/0400.,0700.,1000.,1300.,1900.,2200./
C     DATA TEMP/47.0,46.0,47.0,47.0,46.0,44.0/
C     DATA PRESS/30.42,30.42,30.42,30.40,30.35,30.35/
C
C ********** JAN.30 DATA
C
C     DATA TIME/0400.,1000.,1300.,1600.,1900.,2200./
C     DATA TEMP/43.0,44.0,44.0,43.0,44.0,42.0/
C     DATA PRESS/30.32,30.30,30.26,30.22,30.18,30.17/
C
C ********** INITIALIZE PLOTTER AND SET PAGE SIZE.
C
C     CALL PRTPLT(72,6)
      CALL COMPRS
C     CALL VRSTEC (0,0,0)
C     CALL TEK618
      CALL PAGE (11.,8.5)
C
C ********** MAKE SS AXIS IN INTEGERS.
C
      CALL XINTAX
C
C ********** ORIENT Y AXIS NUMBERS HORIZONTALLY.
C
```

```
      CALL YAXANG (0.0)
C
C ********** SELECT TOTAL PLOT AREA.
C
      CALL AREA2D(8.,5.)
C
C ********** SCALE AND LABEL AXES WITH SELF-COUNTING OPTION.
C
      CALL YNAME('TEMPERATURE (DEGREES F)$',100)
      CALL XNAME ('JANUARY 27, HOURS$',100)
      CALL BASALF('STAND')
C
C ********** CREATE THE HEADING AND SET THE PRINT TYPE.
C
      CALL SWISSM
      CALL HEADIN ('METEOROLOGICAL DATA AT WEST POINT$',100,1.5,1)
      call duplx
C
C ********** DEFINE BOTH AXES AND FRAME THE SUBPLOT AREA.
C
      CALL GRAF(0200.,200.0,2400.,40.0,2.0,54.0)
      CALL THKFRM(.02)
      CALL FRAME
C
C ********** SET UP LEGEND DATA AND TEXT FOR LEGEND NAME.
C
      CALL LINESP (2.0)
      CALL LINES ('TEMPERATURE$',IPAK,1)
      CALL LINES ('PRESSURE$',IPAK,2)
C
C
C ********** FIND SIZE FOR LEGEND.
C
      XW=XLEGND(IPAK,2)
      YW=YLEGND(IPAK,2)
      CALL MYLEGN('OBSERVATION TYPE:$',100)
C
C ********** DEFINE CURVE TYPES AND EXECUTE THE CURVE PLOT.
C
      CALL LEGLIN
      CALL DOT
      CALL CURVE(TIME,TEMP,7,1)
C ********** SET UP SECONDARY Y-AXIS AT RIGHT END.
C
      CALL YGRAXS(30.00,0.05,30.60,5.,'PRESSURE (IN.)$',-100,8.0,0.0)
      CALL DASH
      CALL CURVE(TIME,PRESS,7,1)
C
C
C ********** DRAW THE LEGEND.
C
      CALL LEGEND(IPAK,2,4.50,1.00)
C
C ********** CLOSE OUT METAFILE AND RETURN TO LEVEL ZERO.
C
      CALL ENDPL(0)
      CALL DONEPL
C
C
      STOP
      END
```

```
C    ****************************************************************
C
C       PROGRAM:  RAWRITE
C       DESCRIPTION:  THIS PROGRAM READS MINI-RANGER RATES FROM A FILE
C                     AND CORRECTS THEM FOR A 16 METER OFFSET.  THE
C                     PROGRAM THEN WRITES THE CORRECTED RATES, HEADER
C                     INFORMATION, AND SIGNAL STRENGTHS TO ANOTHER FILE.
C       DATE: MAY 20, 1984
C       AUTHOR:  BRUCE F. HILLARD
C       INPUT/OUTPUT:  BOTH USE A FILEDEF FOR READING AND WRITING.
C       SUBROUTINES:  NONE
C
C    ****************************************************************
C
      CHARACTER BL,A,B,C,D,E
      DATA A,B,C,D,E/'A','B','C','D','E'/
      INTEGER I,J,N,SS,RAT,RATE,TIME,RAVE,CODE,DATE,ANT,BASEL
      DIMENSION BASEL(1500),ANT(1500),CODE(1500),TIME(1500),RAVE(1500),
     1 SS(1500),RAT(1500,10),RATE(1500,10),
     1 LENGTH(1500),DATE(1500)
      REAL LENGTH
C
C    ****************************************************************
C
C     BEGIN READING THE DATA FROM A FILEDEF INTO ARRAYS.
C
C    ****************************************************************
      I=0
    7 I=I+1
      READ(4,201) SS(I),(RAT(I,J),J=1,10),BASEL(I),CODE(I),ANT(I),
     1            RAVE(I),TIME(I)
      DO 100 J=1,10
           RATE(I,J)=RAT(I,J)-16
  100 CONTINUE
      IF(SS(I).EQ.99) GO TO 50
      GO TO 7
   50 CONTINUE
      N=I
C    ****************************************************************
C
C     AT THIS POINT, THE DATA HAS ALL BEEN STORED IN THE ARRAYS SS(I),
C     RATE(I,J),BASEL(I),CODE(I),ANT(I),RAVE(I), AND TIME(I).
C
C    ****************************************************************
C
C    ****************************************************************
C
C     DETERMINE LENGTH,BL, AND DATE AND BEGIN WRITING OUT THE DATA.
C
C    ****************************************************************
      DO 160 I=1,N
            IF(SS(I).EQ.99) GO TO 500
            IF(BASEL(I).EQ.1) GO TO 51
            IF(BASEL(I).EQ.2) GO TO 52
            IF(BASEL(I).EQ.3) GO TO 53
            IF(BASEL(I).EQ.4) GO TO 54
            IF(BASEL(I).EQ.5) GO TO 55
   51                 LENGTH(I)=1061.24
                      BL=A
                      DATE(I)=30
                      GO TO 59
   52                 LENGTH(I)=2417.48
                      BL=B
                      DATE(I)=29
                      GO TO 59
   53                 LENGTH(I)=4083.10
                      BL=C
                      DATE(I)=27
                      GO TO 59
   54                 LENGTH(I)=7016.77
```

```
                    BL=D
                    DATE(I)=28
                    GO TO 59
 55                 LENGTH(I)=9861.08
                    BL=E
                    DATE(I)=28
                    GO TO 59
C    ******************************************************************
C      CHECK FOR A NEW CALIBRATION SET (HEADER).
C    ******************************************************************
 59         IF(I.EQ.1) GO TO 65
 60         IF(SS(I).LE.SS(I-1)) GO TO 80
 65         WRITE(6,202)BL,LENGTH(I),DATE(I),TIME(I),CODE(I),RAVE(I)
C
C    ******************************************************************
C
C      TEST FOR THE ANTENNA TYPE TO BE USED IN THE HEADER.
C
C    ******************************************************************
C
            IF(ANT(I).EQ.1) WRITE(6,203)
            IF(ANT(I).EQ.2) WRITE(6,204)
            IF(ANT(I).EQ.3) WRITE(6,205)
C
      WRITE(6,206)
      WRITE(6,207)
C    ******************************************************************
C
C      BEGIN WRITING OUT THE DATA ITSELF.
C
C    ******************************************************************
C
 80         CONTINUE
            WRITE(6,208) SS(I),(RATE(I,J),J=1,10)
160   CONTINUE
C    ******************************************************************
C
C      FORMAT STATEMENTS:
C
C    ******************************************************************
C
201   FORMAT(I2,2X,10(I4,1X),I1,I1,I1,I2,I4)
202   FORMAT(//2X,'BASE LINE ',A1,2X,'LENGTH = ',F7.2,1X,'METERS',3X,
     1 'JANUARY ',I2,', 1984',2X,I4,1X,'HOURS',/,18X,'CODE: ',I1,4X,
     1 'RANGE AVERAGE SETTING: ',I2)
203   FORMAT(22X,'ANTENNA TYPE: MEDIUM GAIN')
204   FORMAT(22X,'ANTENNA TYPE: OMNIDIRECTIONAL')
205   FORMAT(22X,'ANTENNA TYPE: HIGH GAIN')
206   FORMAT(/,3X,'SIGNAL',15X,'OBSERVED MINI-RANGER RATES')
207   FORMAT(2X,'STRENGTH',2X,'1',4X,'2',4X,'3',4X,'4',4X,'5',4X,'6',
     1 4X,'7',4X,'8',4X,'9',4X,'10')
208   FORMAT(4X,I2,5X,10(I4,1X))
500   CONTINUE
      STOP
      END
```

```
C***********************************************************************
C
C      PROGRAM:  STAT
C      DESCRIPTION:  THIS PROGRAM LISTS THE MEANS AND VARIANCES OF BOTH
C                    OBSERVED RATES AND COMPUTED RANGE ERRORS OF THESIS
C                    MINI-RANGER CALIBRATION DATA.
C      DATE: MAY 20, 1984
C      AUTHOR:  BRUCE F. HILLARD
C      INPUT/OUTPUT:  BOTH USE A FILEDEF FOR READING AND WRITING.
C      SUBROUTINES:  NONE
C
C   *******************************************************************
C
      CHARACTER BL,A,B,C,D,E
      DATA A,B,C,D,E/'A','B','C','D','E'/
      INTEGER I,J,N,SS,RAT,RATE,TIME,RAVE,CODE,DATE,ANT,BASEL
      DIMENSION BASEL(1500),ANT(1500),CODE(1500),TIME(1500),RAVE(1500),
     1 SS(1500),RAT(1500,10),RATE(1500,10),XRATE(1500),SUMM(1500),
     1 LENGTH(1500),DATE(1500),XRERR(1500),VRATE(1500),
     1 VRERR(1500),SUMMM(1500),RERR(1500,10),RATSUM(1500),SUM(1500)
      REAL LENGTH,RERR,RATSUM,XRATE,SUM,SUMM,SUMMM,XRERR,VRATE,VRERR
C
C   *******************************************************************
C
C     BEGIN READING THE DATA FROM A FILEDEF INTO ARRAYS.
C
C   *******************************************************************
      I=0
    7 I=I+1
      READ(4,201) SS(I),(RAT(I,J),J=1,10),BASEL(I),CODE(I),ANT(I),
     1             RAVE(I),TIME(I)
      DO 100 J=1,10
           RATE(I,J)=RAT(I,J)-16
  100 CONTINUE
      IF(SS(I).EQ.99) GO TO 50
      GO TO 7
   50 CONTINUE
      N=I
C   *******************************************************************
C
C     AT THIS POINT, THE DATA HAS ALL BEEN STORED IN THE ARRAYS SS(I),
C     RATE(I,J),BASEL(I),CODE(I),ANT(I),RAVE(I), AND TIME(I).
C
C   *******************************************************************
C
C   *******************************************************************
C
C     DETERMINE LENGTH,BL, AND DATE AND BEGIN WRITING OUT THE DATA.
C
C   *******************************************************************
      DO 160 I=1,N
            IF(SS(I).EQ.99) GO TO 500
            IF(BASEL(I).EQ.1) GO TO 41
            IF(BASEL(I).EQ.2) GO TO 42
            IF(BASEL(I).EQ.3) GO TO 43
            IF(BASEL(I).EQ.4) GO TO 44
            IF(BASEL(I).EQ.5) GO TO 45
   41                  LENGTH(I)=1061.24
                       BL=A
                       DATE(I)=30
                       GO TO 55
   42                  LENGTH(I)=2417.48
                       BL=B
                       DATE(I)=29
                       GO TO 55
   43                  LENGTH(I)=4083.10
                       BL=C
                       DATE(I)=27
                       GO TO 55
   44                  LENGTH(I)=7016.77
```

```
                     BL=D
                     DATE(I)=28
                     GO TO 55
   45                LENGTH(I)=9861.08
                     BL=E
                     DATE(I)=28
                     GO TO 55
C    ******************************************************************
C      BEGIN STATISTICAL CALCULATIONS.
C    ******************************************************************
   55 RATSUM(I)=0.0
      SUM(I)=0.0
      DO 56 J=1,10
               RATSUM(I)=RATSUM(I)+FLOAT(RATE(I,J))
               RERR(I,J)=RATE(I,J)-LENGTH(I)
               SUM(I)=SUM(I)+RERR(I,J)
   56 CONTINUE
      XRATE(I)=RATSUM(I)/10.0
      XRERR(I)=SUM(I)/10.0
      SUMM(I)=0.0
      DO 57 J=1,10
               SUMM(I)=SUMM(I)+((RATE(I,J)-XRATE(I))**2)
   57 CONTINUE
      VRATE(I)=(SUMM(I))/9.0
      SUMMM(I)=0.0
      DO 58 J=1,10
               SUMMM(I)=SUMMM(I)+((RERR(I,J)-XRERR(I))**2)
   58 CONTINUE
      VRERR(I)=(SUMMM(I))/9.0
   59       IF(I.EQ.1) GO TO 65
   60       IF(SS(I).LE.SS(I-1)) GO TO 80
   65       WRITE(7,202)BL,LENGTH(I),DATE(I),TIME(I),CODE(I),RAVE(I)
C
C    ******************************************************************
C
C      TEST FOR THE ANTENNA TYPE TO BE USED IN THE HEADER.
C
C    ******************************************************************
C
            IF(ANT(I).EQ.1) WRITE(7,203)
            IF(ANT(I).EQ.2) WRITE(7,204)
            IF(ANT(I).EQ.3) WRITE(7,205)
C
      WRITE(7,206)
C    ******************************************************************
C
C      BEGIN WRITING OUT THE DATA ITSELF.
C
C    ******************************************************************
C
   80       CONTINUE
            WRITE(7,208) SS(I),XRATE(I),VRATE(I),XRERR(I),VRERR(I)
C           WRITE(7,209) RATSUM(I),SUM(I),SUMM(I),SUMMM(I)
  160 CONTINUE
C    ******************************************************************
C
C      FORMAT STATEMENTS:
C
C    ******************************************************************
C
  201 FORMAT(I2,2X,10(I4,1X),I1,I1,I1,I2,I4)
  202 FORMAT(//2X,'BASE LINE ',A1,2X,'LENGTH = ',F7.2,1X,'METERS',3X,
     1 'JANUARY ',I2,', 1984',2X,I4,1X,'HOURS',/,18X,'CODE: ',I1,4X,
     1 'RANGE AVERAGE SETTING: ',I2)
  203 FORMAT(22X,'ANTENNA TYPE: MEDIUM GAIN')
  204 FORMAT(22X,'ANTENNA TYPE: OMNIDIRECTIONAL')
  205 FORMAT(22X,'ANTENNA TYPE: HIGH GAIN')
  206 FORMAT(/,4X,'SIGNAL',5X,'AVERAGE',7X,'RATE',8X,'AVERAGE',5X,
     1 'RANGE ERROR',/,3X,'STRENGTH',6X,'RATE',6X,'VARIANCE',5X,
     1 'RANGE ERROR',3X,'VARIANCE')
```

```
  208 FORMAT(6X,I2,7X,F6.1,5X,F6.1,8X,F6.1,8X,F6.1)
C 209 FORMAT(4X,'RAISUM= ',F11.1,4X,'SUM= ',F6.1,4X,'SUMM= ',F15.1,4X,
c    1      'SUMMM= ',F6.1)
  500 CONTINUE
      STOP
      END
```

```
C
C
C ********************************************************************
C
C        PROGRAM:  SSPLOT
C        AUTHOR:   BRUCE F. HILLARD
C        DATE:     JUNE 6, 1984
C        PROGRAM DESCRIPTION:  THIS FORTRAN PROGRAM USES DISSPLA
C                              SUBROUTINES TO GENERATE PLOTS OF
C                              MINI-RANGER SIGNAL STRENGTH VERSUS
C                              MEAN RANGE ERROR WITH STANDARD
C                              DEVIATIONS.
C        INPUT:    INPUT COMES FROM A DATA FILE REFERENCED WITH A
C                  FILEDEF.
C        OUTPUT:   THE RESULTANT PLOT CAN BE DIRECTED TO ONE OF THREE
C                  PLOTTERS: VERSATEC 8222A, VERSATEC 0900A, OR A
C                  TEKTRONIX 4631 HARDWARE DEVICE.
C
C*********************************************************************
C
      INTEGER I,J,K,L,M,SS,TIME,RAVE,CODE,ANT,BASEL,
     1        SSA,SS1,SS2,SS3,P,Q,R,S,ANTA,IPAK
      DIMENSION BASEL(1500),ANT(1500),CODE(1500),TIME(1500),
     1 SS(1500),XRERR(1500),XRATE(1500),VRERR(1500),VRATE(1500),
     1 XRERR1(1500),XRERR2(1500),XRERR3(1500),XRERRA(1500),
     1 SSA(1500),SS1(1500),SS2(1500),SS3(1500),RAVE(1500),STD1A(1500),
     1 STD1B(1500),STD2A(1500),STD2B(1500),STD3A(1500),STD3B(1500),
     1 VRERRA(1500),VRERR1(1500),VRERR2(1500),VRERR3(1500),ANTA(1500),
     1 TEMP1(1500),TEMP2(1500),TEMP3(1500),IPAK(100)
      REAL XRERR,XRERRA,XRERR1,XRERR2,XRERR3,XRATE,VRATE,VRERR,
     1 STD1A,STD1B,STD2A,STD2B,STD3A,STD3B,VRERRA,VRERR1,VRERR2,VRERR3,
     1 TEMP1,TEMP2,TEMP3
C
C ********** READ IN THE STAT DATA FROM A FILEDEF.
C
C
      J=0
      K=0
      L=0
      M=0
      I=0
      P=1
      Q=1
      R=1
      S=1
    7 I=I+1
      READ(4,208) SS(I),XRATE(I),VRATE(I),XRERR(I),VRERR(I),BASEL(I),
     1CODE(I),ANT(I),RAVE(I),TIME(I)
      IF(SS(I).EQ.99) GO TO 50
      GO TO 7
   50 CONTINUE
      N=I
C
C ********** AT THIS POINT, ALL THE DATA HAS BEEN STORED IN ARRAYS.
C
C ********** DETERMINE, BY COMPARISONS, THE DATA TO BE PLOTTED.
C
      DO 160 I=1,N
   55          IF(BASEL(I).EQ.5) GO TO 60
               GO TO 160
   60          IF(CODE(I).EQ.0) GO TO 70
               GO TO 160
   70          IF(RAVE(I).EQ.20)GO TO 80
               GO TO 160
   80          SSA(P)=SS(I)
               XRERRA(P)=XRERR(I)
               VRERRA(P)=VRERR(I)
               ANTA(P)=ANT(I)
               P=P+1
  160 CONTINUE
```

```
      J=P-1
C************** AT THIS POINT, ONLY THE "BASE LINE A/CODE 0/RAVE=20"
C               VALUES HAVE BEEN ACCEPTED INTO NEW ARRAYS
C               SUBSCRIPTED BY THE INTEGER P.
C
C ************* NOW LOAD THESE VALUES BY ANTENNA-TYPE INTO THREE
C               SEPARATE ARRAYS AND CALCULATE THEIR STANDARD
C               DEVIATIONS FROM THEIR MEANS.
C
      DO 180 P=1,J
               IF(ANTA(P).EQ.1) GO TO 191
               IF(ANTA(P).EQ.2) GO TO 192
               IF(ANTA(P).EQ.3) GO TO 193
C
  191          SS1(Q)=SSA(P)
               XRERR1(Q)=XRERRA(P)
               VRERR1(Q)=VRERRA(P)
               STD1A(Q)=XRERR1(Q)+SQRT(VRERR1(Q))
               STD1B(Q)=XRERR1(Q)-SQRT(VRERR1(Q))
               Q=Q+1
               GO TO 180
  192          SS2(R)=SSA(P)
               XRERR2(R)=XRERRA(P)
               VRERR2(R)=VRERRA(P)
               STD2A(R)=XRERR2(R)+SQRT(VRERR2(R))
               STD2B(R)=XRERR2(R)-SQRT(VRERR2(R))
               R=R+1
               GO TO 180
  193          SS3(S)=SSA(P)
               XRERR3(S)=XRERRA(P)
               VRERR3(S)=VRERRA(P)
               STD3A(S)=XRERR3(S)+SQRT(VRERR3(S))
               STD3B(S)=XRERR3(S)-SQRT(VRERR3(S))
               S=S+1
               GO TO 180
  180 CONTINUE
      K=Q-1
      L=R-1
      M=S-1
C
C ************* PERFORM THE NECESSARY PLOT/SETUP ROUTINES.
C
C ********** INITIALIZE PLOTTER AND SET PAGE SIZE.
C     CALL PRTPLT(72,6)
C     CALL COMPRS
C     CALL VRSTEC (0,0,0)
      CALL TEK618
      CALL PAGE (11.,8.5)
      CALL BLOWUP(1.25)
C
C ********** MAKE SS AXIS IN INTEGERS
C
      CALL XINTAX
C
C ********** ORIENT Y AXIS NUMBERS HORIZONTALLY.
C
      CALL YAXANG (0.0)
C
C ********** SELECT TOTAL PLOT AREA.
C
      CALL AREA2D(8.,6.)
C
C ********** SCALE AND LABEL AXES WITH SELF-COUNTING OPTION.
C
      CALL YNAME('RANGE ERROR (M) $',100)
      CALL XNAME ('SIGNAL STRENGTHS',100)
      CALL BASALF('STAND')
C
C ********** CREATE THE HEADING AND SET THE PRINT TYPE.
C
```

```
      CALL SWISSM
      CALL HEADIN ('MINI-RANGER III BASELINE CALIBRATION$',100,1.5,1)
C
C ********** DEFINE BOTH AXES AND FRAME THE SUBPLOT AREA.
C
      CALL DUPLX
      CALL GRAF(18.0,1.0,3.0,-10.0,2.0,10.0)
      CALL THKFRM(.02)
      CALL FRAME
C
C ********** SET UP LEGEND DATA AND TEXT FOR LEGEND NAME.
C
      CALL LINESP (2.0)
      CALL LINES ('MEDIUM$',IPAK,1)
      CALL LINES ('OMNI$',IPAK,2)
      CALL LINES ('HIGH$',IPAK,3)
C
C
C ********** FIND SIZE FOR LEGEND.
C
      XW=XLEGND(IPAK,3)
      YW=YLEGND(IPAK,3)
      CALL MYLEGN('ANTENNA TYPE:$',100)
      CALL LEGLIN
C ********** DEFINE CURVE TYPES AND EXECUTE THE CURVES.
C
C ********** PLOT THE MEDIUM GAIN ANTENNA VALUES.
C
      CALL MARKER(15)
      CALL DOT
      CALL THKCRV(.025)
      DO 195 Q=1,K
            TEMP1(Q)=FLOAT(SS1(Q))
  195 CONTINUE
               CALL CURVE(TEMP1,XRERR1,K,1)
C
C *********** PLOT THE OMNIDIRECTIONAL ANTENNA VALUES.
C
      CALL MARKER(16)
      CALL DASH
      CALL THKCRV(.025)
      DO 196 R=1,L
            TEMP2(R)=FLOAT(SS2(R))
  196 CONTINUE
               CALL CURVE(TEMP2,XRERR2,L,1)
C
C ************ PLOT THE HIGH GAIN ANTENNA VALUES.
C
      CALL MARKER(17)
      CALL RESET('DASH')
      CALL THKCRV(.025)
      DO 197 S=1,M
            TEMP3(S)=FLOAT(SS3(S))
  197 CONTINUE
               CALL CURVE(TEMP3,XRERR3,M,1)
C
C ********** OTHER PLOT/LEGEND INFORMATION:
C
      CALL MESSAG('BASELINE E$',100,3.50,5.50)
      CALL MESSAG('RANGE AVERAGE: 20$',100,3.50,5.25)
C     CALL MESSAG('RANGE AVERAGE: 40$',100,3.50,5.25)
C     CALL MESSAG('RANGE AVERAGE: 75$',100,3.50,5.25)
      CALL MESSAG('CODE NO. 0$',100,3.5,5.0)
C     CALL MESSAG('CODE NO. 1$',100,3.5,5.0)
      CALL MESSAG('NOTE: VERTICAL BARS ARE STANDARD DEVIATIONS.$',
     1        100,1.25,0.50)
C
C ********** DRAW THE LEGEND.
C
      CALL LEGEND(IPAK,3,1.0,3.75)
```

```
C
C
C *******     PLOT VERTICAL BARS (STANDARD DEVIATIONS).
C
      CALL BARWID(0.025)
      CALL BARPAT(16)
      CALL VBARS(TEMP1,STD1B,STD1A,K)
      CALL VBARS(TEMP2,STD2B,STD2A,L)
      CALL VBARS(TEMP3,STD3B,STD3A,M)
C
C ********** READ FORMAT STATEMENT.
C
  208 FORMAT(6X,I2,7X,F6.1,8X,F3.1,10X,F4.1,11X,F3.1,3X,I1,I1,I1,I2,I4)
C
C ********** CLOSE OUT METAFILE AND RETURN TO LEVEL ZERO.
C
      CALL ENDPL(0)
      CALL DONEPL
C
C
      STOP
      END
```

```
C
C
C ********************************************************************
C
C        PROGRAM:  WALK
C        AUTHOR:   BRUCE F. HILLARD
C        DATE:     AUGUST 24, 1984
C        PROGRAM DESCRIPTION:  THIS FORTRAN PROGRAM USES DISSPLA
C                              SUBROUTINES TO GENERATE PLOTS OF
C                              BASE LINE DISTANCE VERSUS
C                              MEAN RANGE ERROR.  SIGNAL STRENGTH
C                              VALUES ARE USED AS MARKERS.
C        INPUT:    INPUT COMES FROM A DATA FILE REFERENCED WITH A
C                  FILEDEF.
C        OUTPUT:   THE RESULTANT PLOT CAN BE DIRECTED TO ONE OF THREE
C                  PLOTTERS: VERSATEC 8222A, VERSATEC 0900A, OR A
C                  TEKTRONIX 4631 HARDWARE DEVICE.
C
C********************************************************************
C
      INTEGER I,J,K,TIME,RAVE,CODE,ANT,BASEL,SSA,SS,BASELA,B
     1N,NN,NNN,NNNN,M,MM,MMM,MMMM,P,PP,PPP,PPPP,R,RR,RRR
      DIMENSION BASEL(1500),ANT(1500),CODE(1500),TIME(1500),
     1 SS(1500),XRERR(1500),XRATE(1500),VRERR(1500),VRATE(1500),
     1 XRERRA(1500),SSA(1500),RAVE(1500),BASELA(1500)
      REAL XRERR,XRERRA,XRATE,VRATE,VRERR,L
     1 X4,XX4,X5,XX5,X6,XX6,X7,XX7,X8,XX8,X9,XX9,X10,XX10,
     1 X11,XX11,X12,XX12,X13,XX13,X14,XX14,X15,XX15,X16,XX16,X17,XX17,
     1 X18,XX18
C
C ********** INITIALIZE PLOTTER AND SET PAGE SIZE.
C
C     CALL PRTPLT(72,6)
      CALL COMPRS
C     CALL VRSTEC (0,0,0)
C     CALL TEK618
      CALL PAGE (11.,8.5)
C
C
C ********** ORIENT Y AXIS NUMBERS HORIZONTALLY.
C
      CALL YAXANG (0.0)
C
C ********** SELECT TOTAL PLOT AREA.
C
      CALL AREA2D(8.,6.)
C
C ********** SCALE AND LABEL AXES WITH SELF-COUNTING OPTION.
C
      CALL YNAME('RANGE ERROR (M) $',100)
      CALL XNAME ('BASE LINE DISTANCE (M)$',100)
      CALL BASALF('STAND')
C
C ********** CREATE THE HEADING AND SET THE PRINT TYPE.
C
      CALL HEADIN ('BASE LINE DISTANCE VS. RANGE ERROR$',100,1.5,1)
C
C ********** DEFINE BOTH AXES AND FRAME THE SUBPLOT AREA.
C
      CALL DUPLX
      CALL GRAF(0.0,1000.0,11000.0,-3.0,1.0,6.0)
      CALL THKFRM(.02)
      CALL FRAME
C
C
C ********** OTHER PLOT/LEGEND INFORMATION:
C
      CALL MESSAG('CODE NO. 0$',100,3.0,5.25)
      CALL MESSAG('NUMBERS ARE SIGNAL STRENGTHS $',
     1        100,2.50,5.50)
```

```
C
C
C ********** READ IN THE STAT DATA FROM A FILEDEF.
C
      J=0
      I=0
    7 I=I+1
      READ(4,300) SS(I),XRATE(I),VRATE(I),XRERR(I),VRERR(I),BASEL(I),
     1CODE(I),ANT(I),RAVE(I),TIME(I)
      IF(SS(I).EQ.99) GO TO 50
      GO TO 7
   50 CONTINUE
      N=I
C
C
C ********** READ FORMAT STATEMENT.
C
  300 FORMAT(6X,I2,7X,F6.1,8X,F3.1,10X,F4.1,11X,F3.1,3X,I1,I1,I1,I2,I4)
C
C ********** AT THIS POINT, ALL THE DATA HAS BEEN STORED IN ARRAYS.
C
C ********** SORT OUT THE DESIRED CODE.
C
C
      DO 400 I=1,N
               IF(CODE(I).NE.0) GO TO 400
               J=J+1
               SSA(J)=SS(I)
               XRERRA(J)=XRERR(I)
               BASELA(J)=BASEL(I)
  400 CONTINUE
C
C************** K IS THE TOTAL NUMBER OF POINTS TO BE PLOTTED.
C
      K=J
      B=0
C
C************** DO LOOP THROUGH THE DATA ONCE PER BASE LINE.
C
  500 CONTINUE
      B=B+1
      IF(B.EQ.6) GO TO 2000
C
C************** SET ALL COUNTERS TO ZERO.
C
               N=0
               X4=0.0
               XX4=0.0
               NN=0
               X5=0.0
               XX5=0.0
               NNN=0
               X6=0.0
               XX6=0.0
               NNNN=0
               X7=0.0
               XX7=0.0
               M=0
               X8=0.0
               XX8=0.0
               MM=0
               X9=0.0
               XX9=0.0
               MMM=0
               X10=0.0
               XX10=0.0
               MMMM=0
               X11=0.0
               XX11=0.0
               P=0
```

```
            X12=0.0
            XX12=0.0
            PP=0
            X13=0.0
            XX13=0.0
            PPP=0
            X14=0.0
            XX14=0.0
            PPPP=0
            X15=0.0
            XX15=0.0
            R=0
            X16=0.0
            XX16=0.0
            RR=0
            X17=0.0
            XX17=0.0
            RRR=0
            X18=0.0
            XX18=0.0
C
C************** SORT THE DATA BY BASE LINES AND SIGNAL STRENGTHS.
C
      DO 1000 J=1,K
C
C************** SORT FOR ONE BASE LINE AT A TIME.
C
      IF(BASELA(J).NE.B) GO TO 1000
C
C************** SORT THE SIGNAL STRENGTHS.
C
  100 CONTINUE
      IF(SSA(J).NE.4) GO TO 101
      X4=X4+XRERRA(J)
      N=N+1
      GO TO 1000
  101 CONTINUE
      IF(SSA(J).NE.5) GO TO 102
      X5=X5+XRERRA(J)
      NN=NN+1
      GO TO 1000
  102 CONTINUE
      IF(SSA(J).NE.6) GO TO 103
      X6=X6+XRERRA(J)
      NNN=NNN+1
      GO TO 1000
  103 CONTINUE
      IF(SSA(J).NE.7) GO TO 104
      X7=X7+XRERRA(J)
      NNNN=NNNN+1
      GO TO 1000
  104 CONTINUE
      IF(SSA(J).NE.8) GO TO 105
      X8=X8+XRERRA(J)
      M=M+1
      GO TO 1000
  105 CONTINUE
      IF(SSA(J).NE.9) GO TO 106
      X9=X9+XRERRA(J)
      MM=MM+1
      GO TO 1000
  106 CONTINUE
      IF(SSA(J).NE.10) GO TO 107
      X10=X10+XRERRA(J)
      MMM=MMM+1
      GO TO 1000
  107 CONTINUE
      IF(SSA(J).NE.11) GO TO 108
      X11=X11+XRERRA(J)
      MMMM=MMMM+1
```

```
      GO TO 1000
  108 CONTINUE
      IF(SSA(J).NE.12) GO TO 109
      X12=X12+XRERRA(J)
      P=P+1
      GO TO 1000
  109 CONTINUE
      IF(SSA(J).NE.13) GO TO 110
      X13=X13+XRERRA(J)
      PP=PP+1
      GO TO 1000
  110 CONTINUE
      IF(SSA(J).NE.14) GO TO 111
      X14=X14+XRERRA(J)
      PPP=PPP+1
      GO TO 1000
  111 CONTINUE
      IF(SSA(J).NE.15) GO TO 112
      X15=X15+XRERRA(J)
      PPPP=PPPP+1
      GO TO 1000
  112 CONTINUE
      IF(SSA(J).NE.16) GO TO 113
      XX16=X16+XRERRA(J)
      R=R+1
      GO TO 1000
  113 CONTINUE
      IF(SSA(J).NE.17) GO TO 114
      X17=X17+XRERRA(J)
      RR=RR+1
      GO TO 1000
  114 CONTINUE
      IF(SSA(J).NE.18) GO TO 1000
      X18=X18+XRERRA(J)
      RRR=RRR+1
 1000 CONTINUE
C
C************** COMPUTE THE MEAN RANGE ERROR FOR EACH SIGNAL STRENGTH
C                AND ASSIGN THE BASE LINE LENGTH TO BE PLOTTED.
C
               IF(B.NE.1) GO TO 90
               L=1061.24
               GO TO 600
   90          IF(B.NE.2) GO TO 91
               L=2417.48
               GO TO 600
   91          IF(B.NE.3) GO TO 92
               L=4083.10
               GO TO 600
   92          IF(B.NE.4) GO TO 93
               L=7016.77
               GO TO 600
   93          CONTINUE
               L=9861.08
  600 CONTINUE
C************** COMPUTE THE MEAN RANGE ERRORS.
C
      XX4=X4/FLOAT(N)
      XX5=X5/FLOAT(NN)
      XX6=X6/FLOAT(NNN)
      XX7=X7/FLOAT(NNNN)
      XX8=X8/FLOAT(M)
      XX9=X9/FLOAT(MM)
      XX10=X10/FLOAT(MMM)
      XX11=X11/FLOAT(MMMM)
      XX12=X12/FLOAT(P)
      XX13=X13/FLOAT(PP)
      XX14=X14/FLOAT(PPP)
      XX15=X15/FLOAT(PPPP)
      XX16=X16/FLOAT(R)
```

```
      XX17=X17/FLOAT(RR)
      XX18=X18/FLOAT(RRR)
C
C************** SET THE CHARACTER HEIGHT.
C
      CALL HEIGHT(0.15)
C
C************** PLOT THE VALUES FOR ONE BASE LINE.
C
      IF(XX4.EQ.0.0) GO TO 201
      CALL RLINT(4,L,XX4)
  201 CONTINUE
      IF(XX5.EQ.0.0) GO TO 202
      CALL RLINT(5,L,XX5)
  202 CONTINUE
      IF(XX6.EQ.0.0) GO TO 203
      CALL RLINT(6,L,XX6)
  203 CONTINUE
      IF(XX7.EQ.0.0) GO TO 204
      CALL RLINT(7,L,XX7)
  204 CONTINUE
      IF(XX8.EQ.0.0) GO TO 205
      CALL RLINT(8,L,XX8)
  205 CONTINUE
      IF(XX9.EQ.0.0) GO TO 206
      CALL RLINT(9,L,XX9)
  206 CONTINUE
      IF(XX10.EQ.0.0) GO TO 207
      CALL RLINT(10,L,XX10)
  207 CONTINUE
      IF(XX11.EQ.0.0) GO TO 208
      CALL RLINT(11,L,XX11)
  208 CONTINUE
      IF(XX12.EQ.0.0) GO TO 209
      CALL RLINT(12,L,XX12)
  209 CONTINUE
      IF(XX13.EQ.0.0) GO TO 210
      CALL RLINT(13,L,XX13)
  210 CONTINUE
      IF(XX14.EQ.0.0) GO TO 211
      CALL RLINT(14,L,XX14)
  211 CONTINUE
      IF(XX15.EQ.0.0) GO TO 212
      CALL RLINT(15,L,XX15)
  212 CONTINUE
      IF(XX16.EQ.0.0) GO TO 213
      CALL RLINT(16,L,XX16)
  213 CONTINUE
      IF(XX17.EQ.0.0) GO TO 214
      CALL RLINT(17,L,XX17)
  214 CONTINUE
      IF(XX18.EQ.0.0) GO TO 215
      CALL RLINT(18,L,XX18)
  215 CONTINUE
C
      GO TO 500
 2000 CONTINUE
C
C************* CLOSE OUT METAFILE AND RETURN TO LEVEL ZERO.
C
      CALL ENDPL(0)
      CALL DONEPL
      STOP
      END
```

```
C
C
C ******************************************************************
C
C        PROGRAM:  POLYFIT
C        AUTHOR:   BRUCE F. HILLARD
C        DATE:     SEPTEMBER  1984
C        PROGRAM DESCRIPTION:  THIS FORTRAN PROGRAM, TAKEN FROM
C                              GERALD'S NUMERICAL ANALYSIS BOOK,
C                              FITS POLYNOMIAL CURVES FOR UP TO DEGREE
C                              7 TO THE MEAN RANGE ERROR VALUES
C                              FOR MINI-RANGER CODES.
C
C        INPUT:    MEAN RANGE ERRORS ARE INCLUDED IN A DATA STATEMENT.
C        OUTPUT: THE RESULTS ARE WRITTEN TO A PRINTER OR DISK FILE.
C
C*******************************************************************
C
      IMPLICIT REAL*4 (A-H,O-Z)
      DIMENSION X(100),Y(100), C(100),A(10,11), XN(100)
       DATA X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),
     1 X(12),X(13),
     1 X(14)/17.0,16.0,15.0,14.0,13.0,12.0,11.0,10.0,9.0,8.0,7.0,
     1     6.0,5.0,4.0/
       DATA Y(1),Y(2),Y(3),Y(4),Y(5),Y(6),Y(7),Y(8),Y(9),Y(10),Y(11),
     1 Y(12),Y(13),
     1 Y(14)/0.4,1.4,0.8,-0.3,0.5,0.6,0.8,0.5,0.4,0.0,-0.5,-0.9,0.5,
     1 3.6/
C
C
C THIS PROGRAM IS USED TO IN FITTING A POLYNOMIAL TO A SET OF DATA.
C THE PROGRAM READS IN N PAIRS OF X AND Y VALUES AND COMPUTES
C THE COEFFICIENTS OF THE NORMAL EQUATIONS FOR THE LEAST SQUARES
C METHOD.
C
C PARAMETERS ARE:
C      X,Y       ARRAY OF X AND Y VALUES.
C      N         NUMBER OF DATA PAIRS
C      MS,MF     THE RANGE OF DEGREE OF POLYNOMIALS TO BE COMPUTED.
C                THE MAXIMUM DEGREE IS 9.
C      A         AUGMENTED ARRAY OF THE COEFFICIENTS OF THE NORMAL
C                EQUATIONS.
C      C         ARRAY OF COEFFICIENTS OF THE LEAST SQUARES POLYNOMIALS.
C
C
C
      N=14
      MS=1
      MF=7
C COMPUTE MATRIX OF COEFFICIENTS AND R.H.S. FOR MF DEGREE.
C HOWEVER, FIRST CHECK TO SEE IF MAX DEGREE REQUESTED IS TOO LARGE.
C IT CANNOT EXCEED N-1.  IF IT DOES, REDUCE TO EQUAL
C N-1 AND PRINT MESSAGE.
      IF(MF.LE.(N-1)) GO TO 5
      MF=N-1
      WRITE(6,200) MF
200   FORMAT(/,'DEGREE OF POLYNOMIAL CANNOT EXCEED N-1',//,
     1 'REQUESTED MAXIMUM DEGREE OF POLYNOMIAL TOO LARGE-REDUCED TO',
     1  I3)
5     MFP1=MF+1
      MFP2=MF+2
C PUT ONES INTO A NEW ARRAY.  THIS WILL HOLD POWERS OF THE X VALUES
C AS WE PROCEED.
      DO 10 I=1,N
10    XN(I)=1
C COMPUTE FIRST COLUMN AND N+1 ST COLUMN OF A. I MOVES DOWN THE
C ROWS, J SUMS OVER THE N VALUES.
      DO 30 I=1,MFP1
      A(I,1)=0.0
      A(I,MFP2)=0.0
      DO 20 J=1,N
```

```
      A(I,1)= A(I,1) + XN(J)
      A(I,MFP2)= A(I,MFP2) + Y(J)*XN(J)
20    XN(J)= XN(J) * X(J)
30    CONTINUE
C COMPUTE THE LAST ROW OF A.   I MOVES ACROSS THE COLUMNS,
C J SUMS OVER N VALUES.
C
      DO 50 I=2,MFP1
      A(MFP1,I) = 0.0
      DO 40 J = 1,N
40    XN(J) = XN(J) * X(J)
50    CONTINUE
C NOW FILL IN THE REST OF THE A MATRIX.  I MOVES DOWN THE
C ROWS, J MOVES ACROSS THE COLUMNS.
      DO 70 J = 2,MFP1
      DO 60 I = 1,MF
60    A(I,J) = A(I+1,J-1)
70    CONTINUE
C WRITE OUT THE MATRIX OF NORMAL EQUATIONS.
      WRITE(6,201) ((A(I,J), J = 1,MFP2),I = 1,MFP1)
201   FORMAT(/,9F13.5)
C NOW CALL A SUBROUTINE TO SOLVE THE SYSTEM.  DO THIS FOR EACH DEGREE
C FROM MS TO MS.
C GET THE LU DECOMPOSITION OF A
      CALL LUDCMQ (A, MFP1, 10)
C RESET THE R.H.S. INTO C.  WE NEED TO DO THIS FOR EACH DEGREE.
      MSP1 = MS + 1
      DO 95 I = MSP1,MFP1
      DO 90 J = 1,I
90    C(J) = A(J,MFP2)
      CALL SOLNQ (A, C, I, 10)
      IM1 = I-1
C NOW WRITE OUT THE COEFFICIENTS OF THE LEAST SQ POLYNOMIAL.
      WRITE(6,202) IM1, (C(J), J = 1,I)
202   FORMAT(//,2X,'FOR DEGREE OF ',I2,' COEFFICIENTS ARE: ',/,10X,
     1 11F11.3)
C COMPUTE AND PRINT THE VALUE OF BETA = SUM OF DEVIATIONS SQUARED,
C WHICH IS = (N - 1 - M).
      BETA=0.0
      DO 94 IPT = 1,N
      SUM=0.0
      DO 93 ICOEF = 2,I
               JCOEF= I-ICOEF + 2
               SUM=(SUM + C(JCOEF))*X(IPT)
93    CONTINUE
      SUM=SUM+C(1)
      BETA=BETA + (Y(IPT) - SUM)**2
94    CONTINUE
      BETA=BETA/(N-1)
      WRITE(6,203) BETA
203   FORMAT(1H1,10X, ' BETA IS ',F10.5)
95    CONTINUE
      STOP
      END
C
C
      SUBROUTINE LUDCMQ (A, N, NDIM)
      DIMENSION A(NDIM,NDIM)
C THIS SUBROUTINE FORMS THE LU EQUIVALENT OF THE SQUARE
C COEFFICIENT MATRIX A.  THE LU, IN COMPACT FORM, IS RETURNED
C IN THE A MATRIX SPACE.  THE UPPER TRIANGULAR MATRIX U HAS ONES
C ON ITS DIAGONAL - THESE VALUES ARE NOT INCLUDED IN THE RESULT.
      DO 30 I= 1,N
      DO 30 J =2,N
      SUM=0.
      IF(J.GT.I) GO TO 15
      JM1 = J - 1
      DO 10 K=1,JM1
10    SUM = SUM + A(I,K)*A(K,J)
      A(I,J) = A(I,J) - SUM
```

```
      GO TO 30
15    IM1 = I - 1
      IF(IM1.EQ.0) GO TO 25
      DO 20 K = 1,IM1
20    SUM = SUM + A(I,K)*A(K,J)
C TEST FOR SMALL VALUE ON DIAGONAL.
25    IF(ABS(A(I,I)).LT.0.0000001) GO TO 99
      A(I,J) = (A(I,J) - SUM)/A(I,I)
30    CONTINUE
      RETURN
99    WRITE(6,100) I
100   FORMAT(/,' REDUCTION NOT COMPLETED BECAUSE  ,
     1 SMALL VALUE FOUND FOR DIVISOR IN ROW ',I3)
      RETURN
      END
C
C
      SUBROUTINE SOLNQ (A,B,N,NDIM)
      DIMENSION A(NDIM,NDIM),B(NDIM)
C THIS SUBROUTINE FINDS THE SOLUTION TO A SET OF N LINEAR
C EQUATIONS THAT CORRESPONDS TO THE RIGHT HAND SIDE VECTOR B.
C THE A MATRIX IS THE LU DECOMPOSITION EQUIVALENT TO
C THE COEFFICIENT MATRIX OF THE ORIGINAL EQUATIONS, AS
C PRODUCED BY LUDCMP.  THE SOLUTION VECTOR IS
C RETURNED IN THE B VECTOR.
C DO THE REDUCTION STEP
      B(1) = B(1)/A(1,1)
      DO 20 I = 2,N
      IM1 = I - 1
      SUM = 0.0
      DO 10 K = 1,IM1
10    SUM = SUM + A(I,K)*B(K)
20    B(I) = (B(I) - SUM)/A(I,I)
C NOW WE ARE READY FOR BACK SUBSTITUTION.  REMEBER THAT THE
C ELEMENTS OF U ON THE DIAGONAL ARE ALL ONES.
      DO 40 J = 2,N
      NMJP2 = N - J +2
      NMJP1 = N - J + 1
      SUM = 0.
      DO 30 K = NMJP2,N
30    SUM = SUM + A(NMJP1,K)*B(K)
40    B(NMJP1) = B(NMJP1) - SUM
      RETURN
C
      END
```

```
C
C
C ***********************************************************************
C
C        PROGRAM:  POLY
C        AUTHOR:   BRUCE F. HILLARD
C        DATE:     SEPTEMBER 1984
C        PROGRAM DESCRIPTION:  THIS FORTRAN PROGRAM USES DISSPLA
C                              SUBROUTINES TO GENERATE PLOTS OF
C                              MINI-RANGER RANGE ERRORS THAT ARE
C                              PREDICTED FROM POLYNOMIAL REGRESSION
C                              CURVES.  ALSO PLOTTED ARE THE
C                              MEAN RANGES ERRORS USED TO CREATE
C                              THE REGRESSION CURVES.  THE RANGE
C                              ERRORS ARE ASSUMED TO BE A FUNCTION
C                              OF SIGNAL STRENGTH.
C        INPUT:    PLOT VALUES ARE GENERATED WITHIN THE PROGRAM BY
C                  THE REGRESSION CURVES.  THE MEAN RANGE ERRORS ARE
C                  INPUT THROUGH A DATA STATEMENT.
C        OUTPUT:   THE RESULTANT PLOT CAN BE DIRECTED TO ONE OF THREE
C                  PLOTTERS: VERSATEC 8222A, VERSATEC 0900A, OR A
C                  TEKTRONIX 4631 HARDWARE DEVICE.
C
C***********************************************************************
C
      IMPLICIT REAL*4 (A-H,O-Z)
      DIMENSION X(14),Y(14),Y1(100),Y2(100),Y3(100),X1(100),
     1          X2(100),X3(100),IPAK(100)
      DATA X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11),
     1     X(12),X(13),
     1   X(14)/4.0,5.0,6.0,7.0,8.0,9.0,10.0,11.0,12.0,13.0,14.0,
     1     15.0,16.0,17.0/
      DATA Y(1),Y(2),Y(3),Y(4),Y(5),Y(6),Y(7),Y(8),Y(9),Y(10),Y(11),
     1     Y(12),Y(13),
     1     Y(14)/2.9,0.0,-1.4,-1.3,-2.6,-1.6,0.0,0.1,0.1,0.1,-0.1,0.7,
     1     1.2,1.1/
C
C
C ************** PERFORM THE NECESSARY PLOT/SETUP ROUTINES.
C
C ********** INITIALIZE PLOTTER AND SET PAGE SIZE.
C     CALL PRTPLT(72,6)
      CALL COMPRS
C     CALL VRSTEC (0,0,0)
C     CALL TEK618
      CALL PAGE (11.,8.5)
C     CALL BLOWUP(1.25)
C
C ********** MAKE SS AXIS IN INTEGERS
C
      CALL XINTAX
C
C ********** ORIENT Y AXIS NUMBERS HORIZONTALLY.
C
      CALL YAXANG (0.0)
C
C ********** SELECT TOTAL PLOT AREA.
C
      CALL AREA2D(8.,6.)
C
C ********** SCALE AND LABEL AXES WITH SELF-COUNTING OPTION.
C
      CALL YNAME('RANGE ERROR (M) $',100)
      CALL XNAME ('SIGNAL STRENGTH$',100)
      CALL BASALF('STAND')
C
C
C ********** DEFINE BOTH AXES AND FRAME THE SUBPLOT AREA.
C
      CALL DUPLX
```

```
      CALL GRAF(18.0,1.0,3.0,-4.0,1.0,10.0)
      CALL THKFRM(.02)
      CALL FRAME
C
C************ CREATE THE LEGEND THAT IDENTIFIES EACH PLOT.
C
C
C
C ********** OTHER PLOT/LEGEND INFORMATION:
C
C
C
C**** COMPUTE THE FIRST DEGREE VALUES.
C
9     A1=-0.883
      B1=0.079
C
      TEMP1=4.0
   20 CONTINUE
      DO 200 I=1,65
          X1(I)=TEMP1
          Y1(I)= A1+(B1*X1(I))
          TEMP1=X1(I)+0.20
  200 CONTINUE
C
C
C**** COMPUTE THE SECOND DEGREE VALUES.
C
      A2=4.540
      B2=-1.133
      C2=0.058
C
      TEMP2=4.0
   30 CONTINUE
      DO 300 J=1,65
            X2(J)=TEMP2
            Y2(J)=A2+(B2*X2(J))+(C2*X2(J)**2)
            TEMP2=X2(J)+0.20
  300 CONTINUE
C
C
C**** COMPUTE THE THIRD DEGREE VALUES.
C
      A3=17.337
      B3=-5.661
      C3=0.530
      D3=-0.015
C
      TEMP3=4.0
   40 CONTINUE
      DO 400 K=1,65
            X3(K)=TEMP3
            Y3(K)=A3+(B3*X3(K))+(C3*X3(K)**2)+(D3*X3(K)**3)
            TEMP3=X3(K)+0.20
  400 CONTINUE
C
C *********** SET UP LEGEND INFORMATION.
C
      MAXLIN=LINEST(IPAK,100,25)
1     CALL LINESP(2.0)
2     CALL LINES('COMPUTED MEAN VALUES$',IPAK,1)
3     CALL LINES('FIRST DEGREE VALUES$',IPAK,2)
4     CALL LINES('SECOND DEGREE VALUES$',IPAK,3)
5     CALL LINES('THIRD DEGREE VALUES$',IPAK,4)
6     CALL MYLEGN('CURVE TYPES:',12)
7     CALL LEGLIN
C
C
C**** PLOT THE MEAN ERRORS AND THE COMPUTED VALUES.
C
```

```
      CALL THKCRV(.025)
      CALL CURVE(X,Y,14,0)
C
C
      CALL THKCRV(.025)
      CALL DOT
      CALL CURVE(X1,Y1,65,0)
C
C
      CALL THKCRV(.025)
      CALL DASH
      CALL CURVE(X2,Y2,65,0)
C
C
      CALL THKCRV(.025)
      CALL CHNDOT
      CALL CURVE(X3,Y3,65,0)
C
      CALL LEGEND(IPAK,4,1.0,4.0)
C
C ********** ALL CURVES HAVE BEEN PLOTTED.
C ********** NOW COMPUTE THE M.A.S.S. AND PLOT IT.
C
C     CLAST=X3(1)
C     DO 500 K=2,65
C              CHECK=ABS(X3(K)-CLAST)
C              IF(CHECK.GE.2.0) GO TO 600
C              CLAST=X3(K)
  500 CONTINUE
C
C ******** NOW PLOT THE M.A.S.S.
C
C 600 CONTINUE
C     L=K
C     XF=X3(L)
C     XT=XF
C     YF=Y3(L)+0.5
C     YT=Y3(L)+0.1
C
C     CALL VECTOR(XF,YF,XT,YT,1303)
C     XX=XF-0.3
C     YY=YF+0.7
C     CALL RLMESS('M.A.S.S.$',100,XX,YY)
8     CALL MESSAG('CODE NO. 0$',100,5.0,5.0)
C     CALL MESSAG('CODE NO. 1$',100,5.0,5.0)
C
C
C
C ********** CLOSE OUT METAFILE AND RETURN TO LEVEL ZERO.
C
      CALL ENDPL(0)
      CALL DONEPL
C
C
      STOP
      DEBUG TRACE
      AT 1
      TRACE ON
      END
```

```
C
C ********************************************************************
C
C         PROGRAM:  BASELINE
C         AUTHOR:   BRUCE F. HILLARD
C         DATE:     AUGUST 1985
C         PROGRAM DESCRIPTION:  THIS FORTRAN PROGRAM USES DISSPLA
C                               SUBROUTINES TO GENERATE PLOTS OF
C                               MINI-RANGER RANGE ERROR VERSUS
C                               SIGNAL STRENGTH BY BASE LINE.
C         INPUT:    INPUT COMES FROM A DATA FILE REFERENCED WITH A
C                   FILEDEF.
C         OUTPUT:   THE RESULTANT PLOT CAN BE DIRECTED TO ONE OF THREE
C                   PLOTTERS: VERSATEC 8222A, VERSATEC 0900A, OR A
C                   TEKTRONIX 4631 HARDWARE DEVICE.
C
C*********************************************************************
C
      INTEGER M,A,B,C,D,E,X,XX,I,P,Q,R,S,T,SS,TIME,RAVE,CODE,ANT,BASEL
     1 SSA,SSB,SSC,SSD,SSE,ANTA,IPAK,ANTB,ANTC,ANTD,ANTE,SSX
      DIMENSION BASEL(1500),
     1 ANT(1500),CODE(1500),TIME(1500),XRERRE(1500),
     1 SS(1500),XRERR(1500),XRATE(1500),VRERR(1500),VRATE(1500),
     1 XRERRX(1500),XRERRA(1500),XRERRB(1500),XRERRC(1500),XRERRD(1500),
     1 SSA(1500),SSB(1500),SSC(1500),SSD(1500),SSE(1500),RAVE(1500),
     1 TEMPA(1500),TEMPB(1500),TEMPC(1500),TEMPD(1500),TEMPE(1500),
     1 SSX(1500),TEMPX(1500),TOTAL(1500),P(1500),Q(1500),R(1500),
     1 TOTALA(1500),TOTALB(1500),S(1500),T(1500),
     1 TOTALC(1500),TOTALD(1500),TOTALE(1500)
      REAL XRERR,XRERRA,XRERRB,XRERRC,XRERRD,XRERRE,XRATE,VRERR,
     1 TOTALA,TOTALB,TOTALC,TOTALD,TOTALE,TEMPX,
     1 TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TOTAL,XRERRX
C
C ********** READ IN THE STAT DATA FROM A FILEDEF.
C
      I=0
    7 I=I+1
      READ(4,208) SS(I),XRATE(I),VRATE(I),XRERR(I),VRERR(I),BASEL(I),
     1CODE(I),ANT(I),RAVE(I),TIME(I)
      IF(SS(I).EQ.99) GO TO 50
      GO TO 7
   50 CONTINUE
      N=I
C
C ********** AT THIS POINT, ALL THE DATA HAS BEEN STORED IN ARRAYS.
C
C ********** CALCULATE TOTAL MEAN FOR ALL DATA/CODE.
C
      XX=0
      DO 31 M= 4,18
               TOTAL(M)=0
               X=0
               DO 30 I=1,N
                        IF(CODE(I).NE.0) GO TO 30
                        IF(SS(I).NE.M) GO TO 30
                        TOTAL (M)=TOTAL(M)+XRERR(I)
                        X=X+1
   30          CONTINUE
               XRERRX(M)=TOTAL(M)/FLOAT(X)
               SSX(M)=M
               XX=XX+X
   31 CONTINUE
C
C ********** DETERMINE, BY BASE LINE, THE MEAN RANGE ERRORS.
C
               A=0
               B=0
               C=0
               D=0
               E=0
```

```
C
C
      DO 165 M=4,18
                P(M)=0
                Q(M)=0
                R(M)=0
                S(M)=0
                T(M)=0
                TOTALA(M)=0
                TOTALB(M)=0
                TOTALC(M)=0
                TOTALD(M)=0
                TOTALE(M)=0
                DO 160 I=1,N
                          IF(CODE(I).NE.0) GO TO 160
                          IF(SS(I).NE.M) GO TO 160
                          IF(BASEL(I).NE.1) GO TO 60
                          TOTALA(M)=TOTALA(M)+XRERR(I)
                          P(M)=P(M)+1
                          GO TO 160
   60                     IF(BASEL(I).NE.2) GO TO 70
                          TOTALB(M)=TOTALB(M)+XRERR(I)
                          Q(M)=Q(M)+1
                          GO TO 160
   70                     IF(BASEL(I).NE.3) GO TO 80
                          TOTALC(M)=TOTALC(M)+XRERR(I)
                          R(M)=R(M)+1
                          GO TO 160
   80                     IF(BASEL(I).NE.4) GO TO 90
                          TOTALD(M)=TOTALD(M)+XRERR(I)
                          S(M)=S(M)+1
                          GO TO 160
   90                     TOTALE(M)=TOTALE(M)+XRERR(I)
                          T(M)=T(M)+1
  160 CONTINUE
                          SSA(M)=SS(I)
                          SSB(M)=SS(I)
                          SSC(M)=SS(I)
                          SSD(M)=SS(I)
                          SSE(M)=SS(I)
C
C************** NOW CALCULATE THE MEAN RANGE ERROR FOR EACH SIGNAL
C                STRENGTH FOR EACH BASE LINE.
C
                XRERRA(M)=TOTALA(M)/FLOAT(P(M))
                XRERRB(M)=TOTALB(M)/FLOAT(Q(M))
                XRERRC(M)=TOTALC(M)/FLOAT(R(M))
                XRERRD(M)=TOTALD(M)/FLOAT(S(M))
                XRERRE(M)=TOTALE(M)/FLOAT(T(M))
                A=A+P(M)
                B=B+Q(M)
                C=C+R(M)
                D=D+S(M)
                E=E+T(M)
  165 CONTINUE
C
C
C
C ************* PERFORM THE NECESSARY PLOT/SETUP ROUTINES.
C
C ********** INITIALIZE PLOTTER AND SET PAGE SIZE.
C
C     CALL PRTPLT(72,6)
C     CALL COMPRS
C     CALL VRSTEC (0,0,0)
      CALL TEK618
      CALL PAGE (11.,8.5)
C     CALL BLOWUP(1.25)
C
C ********** MAKE SS AXIS IN INTEGERS
```

```
C
      CALL XINTAX
C
C ********** ORIENT Y AXIS NUMBERS HORIZONTALLY.
C
      CALL YAXANG (0.0)
C
C ********** SELECT TOTAL PLOT AREA.
C
      CALL AREA2D(8.,6.)
C
C ********** SCALE AND LABEL AXES WITH SELF-COUNTING OPTION.
C
      CALL YNAME('RANGE ERROR (M) $',100)
      CALL XNAME ('SIGNAL STRENGTHS',100)
      CALL BASALF('STAND')
C
C ********** CREATE THE HEADING AND SET THE PRINT TYPE.
C
C     CALL SWISSM
      CALL HEADIN ('MINI-RANGER III BASE LINE CALIBRATIONS',100,1.5,1)
C
C ********** DEFINE BOTH AXES AND FRAME THE SUBPLOT AREA.
C
      CALL DUPLX
      CALL GRAF(18.0,1.0,3.0,-6.0,2.0,10.0)
      CALL THKFRM(.02)
      CALL FRAME
C
C ********** SET UP LEGEND DATA AND TEXT FOR LEGEND NAME.
C
      CALL LINESP (2.0)
      CALL LINES ('CUMMULATIVE$',IPAK,1)
      CALL LINES ('A - 1061$',IPAK,2)
      CALL LINES ('B - 2417$',IPAK,3)
      CALL LINES ('C - 4083$',IPAK,4)
      CALL LINES ('D - 7017$',IPAK,5)
      CALL LINES ('E - 9861$',IPAK,6)
C
C
C ********** FIND SIZE FOR LEGEND.
C
      XW=XLEGND(IPAK,6)
      YW=YLEGND(IPAK,6)
      CALL MYLEGN('BASE LINE-LENGTH (M)$',100)
      CALL LEGLIN
C
C ********** PLOT BASE LINE A VALUES.
C
      CALL MARKER(15)
      CALL DOT
      CALL THKCRV(.025)
      DO 195 M=4,18
            TEMPA(M)=FLOAT(SSA(M))
  195 CONTINUE
            CALL CURVE(TEMPA,XRERRA,A,1)
C
C *********** PLOT BASE LINE B VALUES.
C
      CALL MARKER(15)
      CALL DASH
      CALL THKCRV(.025)
      DO 196 M=4,18
            TEMPB(M)=FLOAT(SSB(M))
  196 CONTINUE
            CALL CURVE(TEMPB,XRERRB,B,1)
C
C ************ PLOT BASE LINE C VALUES.
C
      CALL MARKER(15)
```

```
      CALL CHNDOT
      CALL THKCRV(.025)
      DO 197 M=4,18
            TEMPC(M)=FLOAT(SSC(M))
  197 CONTINUE
            CALL CURVE(TEMPC,XRERRC,C,1)
C
C ************* PLOT BASE LINE D VALUES.
C
      CALL MARKER(15)
      CALL CHNDSH
      CALL THKCRV(.025)
      DO 198 M=4,18
             TEMPD(M)=FLOAT(SSD(M))
  198 CONTINUE
             CALL CURVE(TEMPD,XRERRD,D,1)
C
C ************* PLOT BASE LINE E VALUES.
C
      CALL MARKER(15)
      CALL MRSCOD(2,6,5.,2.,2.,7.,2.)
      CALL THKCRV(.025)
      DO 199 M=4,18
             TEMPE(M)=FLOAT(SSE(M))
  199 CONTINUE
             CALL CURVE(TEMPE,XRERRE,E,1)
C
C
C ************   PLOT CUMMULATIVE VALUES.
C
      CALL MARKER(15)
      CALL RESET ('MRSCOD')
      CALL THKCRV(.025)
      DO 200 M=4,18
               TEMPX(M)=FLOAT(SSX(M))
  200 CONTINUE
               CALL CURVE(TEMPX,XRERRX,XX,1)
C
C ********** OTHER PLOT/LEGEND INFORMATION:
C
      CALL MESSAG('CODE NO. 0$',100,4.5,5.0)
C     CALL MESSAG('CODE NO. 1$',100,4.5,5.0)
C
C ********** DRAW THE LEGEND.
C
      CALL LEGEND(IPAK,6,1.0,3.75)
C
C
C
C ********** READ FORMAT STATEMENT.
C
  208 FORMAT(6X,I2,7X,F6.1,8X,F3.1,10X,F4.1,11X,F3.1,3X,I1,I1,I1,I2,I4)
C
C ********** CLOSE OUT METAFILE AND RETURN TO LEVEL ZERO.
C
      CALL ENDPL(0)
      CALL DONEPL
C
C
      STOP
      END
```

# LIST OF REFERENCES


1. Laurila, S. H., Electronic Surveying and Navigation, John Wiley and Sons, 1976.

2. Casey, M. J., "Improving the Performance of the Motorola MRS," Lighthouse, Edition No. 24, pp. 5-9, November 1981.

3. Jones, E. E., Mini-Ranger III Operation and Installation Manual, Pacific Marine Center, National Ocean Survey, 1981.

4. Casey, M. J., "Quality Control and the Motorola Mini-Ranger," Hydrographic Journal, No. 23, January 1982.

5. PMC OPORDER, Pacific Marine Center, National Ocean Service, National Oceanic and Atmospheric Administration, Revised through January 1984.

6. Newell, V. E. and Winter, D. D., "Application of the Global Positioning System to Nearshore Hydrographic Surveys," Masters Thesis, Naval Postgraduate School, September 1981.

7. Dunn, P. D. and Higgs, R. H., "Benefits of Early Implementation of a Global Positioning System for Hydrographic Surveys," NOS 1984 Hydrographic Conference Proceedings, pp. 80-85.

8. NOAA/NOS In-house Memo, "Mini-Ranger Calibration Distances," PMC Electronics Branch, May 3, 1983.

9. NOAA/NOS In-house Memo, "Suggested Thesis Topics," SDS III Development Group, 1983.

10. Mini-Ranger III Positioning System Maintenance Manual, Motorola Inc., February 1981.

11. DISSPLA Pocket Guide, Current with Version 9.0, Integrated Software Systems Corporation, October 1981.

12. Gerald, C. F., Applied Numerical Analysis, Addison-Wesley Publishing Company, May 1980.

## INITIAL DISTRIBUTION LIST

| | | No. Copies |
|---|---|---|
| 1. | Defense Technical Information Center<br>Cameron Station<br>Alexandria, VA 22304-6145 | 2 |
| 2. | Library, Code 0142<br>Naval Postgraduate School<br>Monterey, CA 93943 | 2 |
| 3. | Chairman, Department of Oceanography<br>Code 68Mr<br>Naval Postgraduate School<br>Monterey, CA 93943 | 1 |
| 4. | NOAA Liaison Officer<br>Post Office Box 8688<br>Monterey, CA 93943 | 1 |
| 5. | Lt. Bruce Hillard, NOAA<br>NOAA Ship DAVIDSON<br>1801 Fairview Ave., East<br>Seattle, WA 98102 | 2 |
| 6. | Office of the Director<br>Naval Oceanography Division (OP-952)<br>Department of the Navy<br>Washington, D.C. 20350 | 1 |
| 7. | Commander<br>Naval Oceanography Command<br>NSTL,MS 39529 | 1 |
| 8. | Commanding Officer<br>Naval Oceanographic Office<br>Bay St. Louis<br>NSTL, MS 39522 | 1 |
| 9. | Commander Officer<br>Naval Ocean Research and Development Activity<br>Bay St. Louis<br>NSTL, MS 39522 | 1 |
| 10. | Chief of Naval Research<br>800 N. Quincy Street<br>Arlington, VA 22217 | 1 |
| 11. | Chairman, Oceanography Department<br>U. S. Naval Academy<br>Annapolis, MD 21402 | 1 |
| 12. | Chief, Hydrographic Programs Division<br>Defense Mapping Agency (Code PPH)<br>Building 56<br>U.S. Naval Observatory<br>Washington, D. C. 20305-3000 | 1 |

13. Associate Deputy Director for Hydrography 1
Defense Mapping Agency (Code DH)
Building 56
U.S. Naval Observatory
Washington, D.C. 20305-3000

14. Topographic Sciences Department
Code TSD-MC
Defense Mapping School
Ft. Belvoir, VA 22060-5828

15. Director Charting and Geodetic Services 1
N/CG, Room 1006, WSC-1
National Oceanic and Atmospheric Administration
Rockville, MD 20852

16. Chief, Nautical Charting Division 1
N/CG2, Room 1026, WSC-1
National Oceanic and Atmospheric Administration
Rockville, MD 20852

17. Chief, Hydrographic Surveys Branch 1
N/CG24, Room 404, WSC-1
National Oceanic and Atmospheric Administration
Rockville, MD 20852

18. Program Planning, Liaison, and Training Div. 1
NC2, Room 105, Rockwall Building
National Oceanic and Atmospheric Administration
Rockville, MD 20852

19. Director, Pacific Marine Center 1
N/MOP
Nation Ocean Service, NOAA
1801 Fairview Avenue, East
Seattle, WA 98102

20. Director, Atlantic Marine Center 1
N/MOA
National Ocean Service, NOAA
439 West York Street
Norfolk, VA 23510

21. Chief, Program Services Division 1
N/MOP2
Pacific Marine Center
1801 Fairview Ave., East
Seattle, WA 98102

22. Chief, Program Services Division 1
N/MOA2
National Ocean Service, NOAA
439 West York Street
Norfolk, VA 23510

23. Nicholas E. Perugini 1
NOAA Ship RAINIER
1801 Fairview Avenue, East
Seattle, WA 98102

24. Mr. Evan D. Howard 1
1720 Alta Vista Drive
Bakersfield, CA 93305

25. LCDR Alan D. Anderson 1
1404 Post Lane
Bowie, MD 20716

26. Mrs. Margaret Hillard 1
463 G St.
Chula Vista, CA 92010

27. Mrs. Pamela Self 1
3000 Cowell Blvd., #182
Davis, CA. 95616

219521

Thesis
H53341 Hillard
c.1 Base-line calibrations of the Mini-Ranger III and the role of signal strength in correcting real-time hydrographic position data.